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ANTIBIOTICS: Risks In Their Use
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A Note Of Urgency

If you'd like to make an interesting appraisal of the nature of agricultural science just a generation ago, pick up a copy of the 1943-47 USDA Yearbook, *Science In Farming*, as we did recently. A hefty 944-page volume, it was crammed with new information designed to help a nation that had just turned in its swords for plowshares.

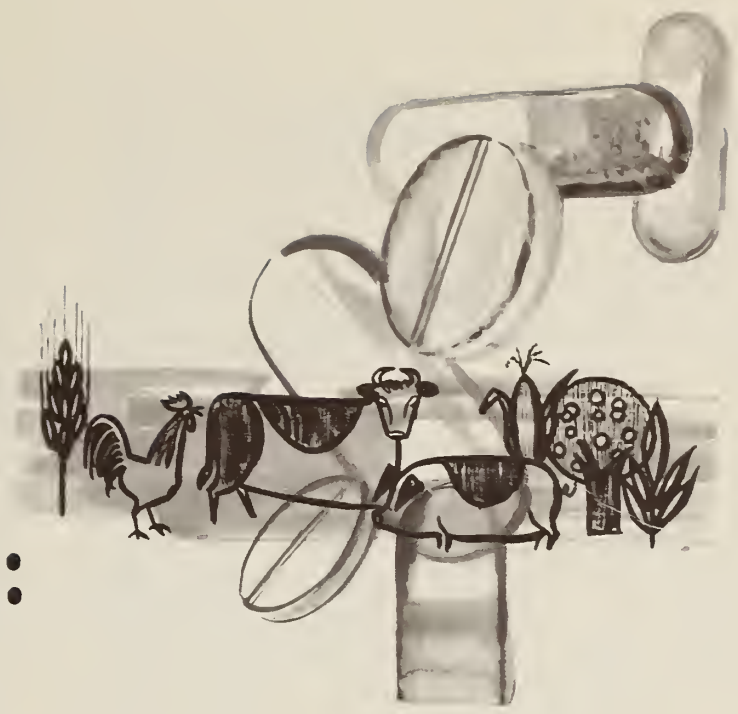
Make no mistake about it. The scope and depth of research in those early post-war years clearly deserved a label of excellence. But if you compare this yearbook—or at least certain sections of it—with a typical issue of *Review* such as this one, some significant differences quickly become apparent.

For example, nowhere in the yearbook can you find any reference to soil pollution. The topic of antibiotics received only a token treatment, for, as the yearbook pointed out, even penicillin was still a laboratory curiosity in the summer of 1941. The author of a slim chapter on rice took no note of an impending world shortage of this important grain. Entomologists, we gathered, were excited about a new pesticide—DDT. Dr. Mitchell's chapter on plant regulators contained only 10 literature references; his article in this issue lists 80 references, most of which carry a date of 1965 or 1966.

Speaking in simple terms, we might say that agricultural scientists today are confronted with a whole new set of problems and values. Hence, an agency like USDA suddenly finds itself catapulted out of the comfortable spot of, say, deciding what fertilizer to recommend for the back forty. And the complexity and urgency of the situation show up when we realize that these problems and values now concern not only urban people, but indeed those in the outermost reaches of the globe. Several of our authors in this issue mince no words in identifying areas of urgency, as they see them. Finding the proper solutions, we suspect, will not be an easy task.

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ANTIBIOTICS:

Risks in Their Use for Non-Medical Purposes

NELSON B. KING AND EARL J. SPLITTER

Antibiotics are being used in the treatment of diseases of humans, animals and plants, as growth promotants in animal feeds and to a lesser extent as preservatives for food. Extensive use of these drugs may contribute to the development of strains of micro-organisms which are resistant to antibiotics and, thus, reduce the effectiveness of the antibiotics on which physicians and veterinarians rely in treating infectious diseases.

It has been known for some time that certain bacteria can develop resistance to antibiotics. It was believed that this resistance was due to mutations that made bacteria resistant to a particular antibiotic.

Studies made in Japan in 1959, later confirmed in Britain and now in this country, have shown a second and perhaps more rapid source of resistance. In effect, it has been found that resistant bacteria can transmit their drug resistance to drug-sensitive bacteria.

Some research workers and some practitioners believe that the development of antibiotic-resistant micro-organisms may be due, in part, to the widespread feeding of antibiotics to livestock and poultry, as well as to their prophylactic and therapeutic use.

CHANGES IN THE NATURE OF DISEASE

Regardless of the specific nature of their etiological agents and their pathological manifestations, microbial diseases can have two different origins—exogenous or endogenous.

Many pathological processes are the direct outcome of exposure to a virulent pathogen. Smallpox, malaria, syphilis, yellow fever, hog cholera, foot-and-mouth disease, brucellosis, rabies, etc., are diseases that can usually be traced to an exposure to the responsible microbial agent; the pathological phenomena then usually develop within a fairly predictable period of time after exposure. This infectious kind of microbial disease, with an exogenous origin, is still of immense importance throughout the world, but it has become less of a menace in communities in the United States, because of the development of vaccines, efficient diagnostic techniques, and antimicrobial therapy.

In contrast, the microbial diseases now gaining prominence, especially in the prosperous countries of the Western World, are often caused by the endogenous microbes formerly regarded as essentially harmless; that is, coliforms and other gram-negative bacilli, various kinds of yeasts, fungi and probably

many viruses, known and unknown. Even though their virulence is low, these organisms can cause serious pathological states under certain circumstances (6).¹

Endogenous microbial diseases have always been responsible for much of human and animal misery, but two developments have made them more obvious and perhaps increased their relative importance during recent years. One is that as the acute exogenous infectious processes are being brought under control, it becomes easier to recognize microbial diseases of endogenous origin. The other development is that, paradoxically enough, many therapeutic and control measures introduced by modern science favor the proliferation of certain components of the endogenous flora and thus allow them to cause disease. For example, enteritis and mastitis of animals caused by staphylococci, yeasts, or fungi frequently occur when the stabilizing ecology is disturbed by administering antimicrobial drugs.

The increasing prominence of endogenous microbial diseases has thus brought to the fore an aspect of the problem of infection that has long been known but grossly neglected; namely, that various microbial agents, including the classical pathogens, can exist and persist in the tissues without causing clinical signs.

In classical infections of exogenous origin, the determining etiological event of the disease is exposure to the infective micro-organism. In endogenous microbial disease, the immediate cause is the environmental factor that upsets the biological equilibrium normally existing between the host and microbial agents.

DEVELOPMENT OF RESISTANCE

Although most antibiotics currently being used have a wide margin of safety, untoward effects have been described in numerous reports in medical literature. The reactions have been the emergence of antibiotic-resistant bacteria, hypersensitivity, toxicity, and super-infection or overgrowth of indigenous flora resulting in a pathogenic process; that is, candidiasis, infections due to *Aerobacter aerogenes*, *Proteus* organisms, *Pseudomonas aeruginosa*, *E. coli*, *Staphylococcus aureus*, etc.

The occurrence of all types of septicemia in Greater Cincinnati hospitals was reported to have risen significantly over the last ten years (1). Although cases due to gram-positive organisms remained essentially the same, gram-negative septicemia rose from 26 percent of the 1955 load to 76.2 percent by 1965. Probably the most important finding was that, of 124 patients who began antibiotic therapy prior to development of the gram-negative infection, 67 percent died. By comparison, mortality was 54 percent among the 181 that had received no antibiotic therapy prior to the infection. Mortality was also higher among the group treated prior to gram-positive septicemia. The *S. aureus* cases had a death rate of 64 percent with and 46 percent without antibiotic pretreatment.

Critical research studies are being conducted to delineate the mechanism of gram-negative bacilli's rise to pathogenicity. Early results confirm the impression that antibiotic depression of sensitive organisms creates a void into which resistant bacteria emerge.

Analogous situations appear to exist in medical and veterinary hospitals throughout the United States. Some researchers theorize that what is happening in the closed world of the hospital can also happen outside; for example, animal diseases such as mastitis and enteric diseases of calves and swine.

The effect of antibiotic therapy of bovine mastitis on *S. aureus* has been studied by Wilson (22). The percent of strains of *S. aureus* resistant to penicillin in 1954-55 was 40.6. This figure had risen to 70.6 by 1960-61. Strains resistant to streptomycin were 1.0 percent in 1954-55 and 20 percent in 1960-61. Resistance to chlortetracycline and oxytetracycline was 0 and 0.5 percent in 1954-55 and 4.3 and 6.0 percent, respectively, in 1960-61.

Smith and Crabb (17) compared the incidence of tetracycline-resistant *E. coli* in the feces of pigs and chickens on farms where tetracycline feeding was practiced with the incidence on farms where the antibiotic was not fed. *E. coli* in most of the tetracycline-fed animals were tetracycline resistant. Resistant *E. coli* were either absent or present in small numbers in animals that had received no tetracycline in feed. Saunders *et al.* (14) in their studies on neonatal diarrhea in pigs observed that when the disease occurred on farms where tetra-

¹ Italic numbers in parentheses refer to Literature Cited p. 8.

cyclines were fed, the *E. coli* involved were tetracycline resistant. Roberts and Valley (13) examined 101 strains of *E. coli*, considered of etiological importance in outbreaks of disease in pigs, and reported that 30 percent were resistant to both oxytetracycline and chlortetracycline.

Sojka and Carnaghan (16) reported a remarkable increase in proportion of tetracycline-resistant *E. coli* implicated in poultry disease between 1957 and 1960. In 1957 only 3.5 percent of *E. coli* examined were resistant to chlortetracycline or oxytetracycline. In 1958 the figure had increased to 20.5 percent, by 1959 to 40.9 percent and by 1960 63.2 percent of the strains of *E. coli* examined were resistant.

The emergence of resistant *E. coli* following therapeutic use of antibiotics has been observed more commonly in calves than in pigs. The reason is that these agents are administered more frequently to calves as a treatment for diarrhea.

Coinciding with the introduction of tetracyclines as dietary additives, there has been an increased incidence in poultry of tetracycline-resistant strains of salmonellae—bacteria which are pathogenic to man and animals.

Smith and Crabb (18) cited evidence that indicated that the practice of feeding antibiotics also gave rise to resistant bacterial flora in regions of the body other than the alimentary tract; namely, the skin and nose of pigs and chickens.

Osborn, Mataney and Pomeroy (12) reported that a single injection of streptomycin into a bird appeared to induce strains of *Mycoplasma gallisepticum* that were streptomycin resistant. These workers also produced tetracycline-resistant strains of *M. gallisepticum* in turkeys by administering high levels of tetracyclines for long periods of time. The resistant strains produced were egg-transmitted from the treated hens to their progeny.

Smith (19) stated that in his opinion, widespread use of antibiotics not only is causing the emergence of antibiotic-resistant strains of potentially pathogenic bacteria, but also that these resistant strains are now causing a considerable proportion of the disease previously caused by sensitive ones. He said there was no evidence to indicate the resistant strains were more virulent than the antibiotic-sensitive counterparts. The character of animal disease in Britain had not been altered in any observable

way other than in its chemotherapy. The main consequence of the increasing incidence of resistant strains of bacteria was that the treatment of many diseases was becoming more difficult because the choice of drugs in any outbreak either (a) had to be the subject of intelligent guesswork, or (b) had to await, where practicable, the result of sensitivity tests.

INFECTIOUS RESISTANCE

More recent experiments have provided new information on an extraordinary but little-known bacterial phenomenon—transferrable drug resistance. Japanese workers (21) were the first to report that resistance in a given species was not necessarily the result of a change mutation in a species, followed by natural selection of the resistant strain. Instead, the genetic-determinants for resistance—and usually for multiple resistance to several antibiotics—could be transferred from cells of one strain of bacteria to cells of another or of another species, genus, or even family. The acquisition of resistance of *Shigella dysenteriae* depended on the transfer of an extra-chromosomal genetic element referred to as R factors, located in the cytoplasm of the cell, during the cell-to-cell mating process known as conjugation.

The first report of R factors outside Japan came from Britain in 1962 (4), and by 1965 extensive surveys of their distribution as well as studies of their fundamental properties had been carried out there as well as in Japan. R factors had also been reported in other European countries and in Israel. The first clinical study of R factors in the United States was reported by Kabins and Cohen (10). These investigations stressed the present widespread occurrence of enteric bacteria harboring R factors and emphasized the threat to antibiotic therapy posed by these infectious agents as well as a need to monitor their spread.

NONMEDICAL USES OF ANTIBIOTICS

In 1961 more than half of the total United States antibiotic production was being used for nonmedical purposes—feed supplements, crop protection, and food preservation. The antibiotics of medical importance are also the antibiotics of nonmedical

importance. This fact complicates the role of regulatory agencies as they are confronted with the problem of potential public health hazards such as toxicity, hypersensitivity, and emergence of microbial resistance.

Antibiotics As Feed Supplements

Excellent reviews on the use of antibiotics in animal nutrition have emphasized the fact that antibiotics stimulate appetite, increase food efficiency, reduce requirements for vitamins, increase survival, and increase growth rate. Evidence has been clear that antibiotics are effective mainly in the early growing period and particularly in situations in which animals are undergoing stress. The most frequently used antibiotics for promoting animal growth are penicillin, chlortetracycline, oxytetracycline, bacitracin, erythromycin, oleandomycin, spiramycin, streptomycin, and tylosin. Increased growth gains have been demonstrated for poultry, swine, calves, lambs, and fur-bearing animals.

Chickens were the first animals in which antibiotic growth effect was observed. Today, the use of antibiotics in commercial poultry growing feeds is common practice. Under most conditions, 5 to 20 percent increase in growth rates may be expected when antibiotics are fed at levels of 2 to 10 p.p.m.

Antibiotics have been shown to have their greatest effect on growth of chicks reared in an old environment. Various workers have reported that continued feeding of antibiotics in a given environment resulted in a gradually decreased growth response. Others have reported that new antibiotics (not previously used in feeds) stimulated growth, whereas antibiotics used for some time in feeds did not. Heth and Bird (9) found no difference in growth response where antibiotics were fed over an extended period. In a more recent study (11) penicillin, erythromycin, bacitracin and tylosin fed to chicks over a period of three years, consistently produced greater response when they were first fed, or if fed only occasionally. These investigators theorized that the reduced growth response was due to the development of resistance by the intestinal microflora. These data further suggested that routine switching of antibiotics may be necessary to obtain a consistent growth response.

The practical effective feeding level of suitable antibiotics for swine is approximately 5 mg./lb. of feed. Prophylactic and therapeutic levels commonly used in controlling disease are 30 to 100 times as high. Antibiotics are effective in either dry-lot or pasture feeding. Their use increases growth rate by 10–20 percent from weaning to 200 lbs. under average feed-lot conditions. During this period, feed consumption increases 5–10 percent. The saving amounts to about 5 percent of feed required per unit of gain in growing and fattening pigs.

Although there is a very wide variation both in the nature and extent of the response of calves and lambs to antibiotic treatment, the feeding of antibiotics has generally been reported to increase growth rate, feed consumption, and efficiency of feed utilization of young calves and lambs and to reduce the incidence of certain diseases. No effect on milk production and feed consumption was found when chlortetracycline was fed to mature lactating dairy cows which received 130–700 mg. daily for varying periods of time.

The experimental work with beef cattle in which favorable results were reported was carried out principally with chlortetracycline. A level of approximately 10 mg./100 lb. of body weight gave best responses, especially when animals were on rations high in roughage. Setbacks appeared to occur when antibiotics were given at high levels, particularly to animals that received high concentrate diets.

A variable but predominantly favorable effect was obtained when lambs were fed a low level of chlortetracycline (approximately 10 mg./lb. of feed). High dosage with antibiotics appeared to cause digestive disturbances.

In general, levels of antibiotics in feeds have been divided into "low-level feeding," "prophylactic feeding," and "therapeutic feeding." Unfortunately, these levels are not clearly defined nor are they always closely observed. In the United States, low-level refers to feeding of amounts up to 50 p.p.m. Prophylactic level is assumed to be 100–400 p.p.m. Still higher levels of antibiotic—up to 2,000 p.p.m.—are often used when necessary to treat disease. All too often, prophylactic feeding is used routinely to prevent disease even though the suspected disease may not be in the herd or flock. There is much evidence to indicate that the "therapeutic level" feeding is not always used as intended.



Information pertaining to the effect of these levels on microbial resistance and tissue residues is inadequate for assessing potential health hazards to man and animals. This is unquestionably a neglected area of research.

Investigations by Broquist and Kohler (3) showed that chlortetracycline was not present in detectable amounts in the serum or tissues of animals fed 10–20 gm. per ton of feed. When the antibiotic was fed to chickens and pigs for an extended period of time at levels above 50 gm. per ton, the antibiotic could be detected in the serum. At levels of 1,000 gm. per ton, the antibiotic could be recovered from tissue at a level of 1 part per 1,000 parts of tissue.

Analyzing the tissue residue following use of antibiotics in feeds has not yet been done on a large scale. Although there are data which indicate that high-level feeding is required to achieve tissue levels, it is not known how many animals come to slaughter following high-level (prophylactic or therapeutic)

feeding. The effects of antibiotic administration on the microbial ecology may be of greater importance, but this effect too is not well documented.

A few limited studies have been carried out to investigate specifically the effect of levels of chlortetracycline or oxytetracycline (when used as a food preservative) on human intestinal flora. In one study, chlortetracycline was administered to 5 healthy adults in a daily dose of 0.0–20 mg. for 20–107 days. Skin reaction for sensitivity to the antibiotic and change in the flora were observed. In subjects given daily doses of 10 to 20 mg., there was a tendency toward constipation and an increase in colon bacilli and enterococci in the stool. Skin sensitivity to the drug was not observed. In all cases, resistant strains emerged during drug administration, especially among strains of colon bacilli which were found to be resistant to 100 $\mu\text{g.}/\text{ml.}$ However, these strains disappeared after discontinuing the drug. Coliform resistance appeared to develop when more than 25 mg. of chlortetracycline

per kilogram of food was present. The resistant flora disappeared when the antibiotic was not included in the food. Goldberg *et al.* (7), working with 46 persons fed 10 mg. oxytetracycline per kilogram of food, found that (a) oxytetracycline-induced resistance was transitory, (b) that no detectable blood levels appeared and (c) that hypersensitivity to the drug did not occur. In a later study, Goldberg concluded that it was questionable that any hazard existed from ingestion of oxytetracycline or chlortetracycline at levels in foods below 10 p.p.m.

Passage experiments carried on by Smith and Halls (20) revealed a considerable difference in stability between multiple-resistant strains. It was apparent that under natural conditions in a drug-free environment some of them did lose at least part of their resistance pattern. All of the nonpathogenic *E. coli* strains tested that were only tetracycline-resistant showed no loss of resistance on passage. This finding confirmed earlier work (17) which showed that tetracycline-resistant organisms still dominated the *E. coli* flora of the feces of pigs 3 to 7 months after tetracyclines had been removed from the feed.

Penicillin is not used for food preservation because of its potential ability to stimulate allergic responses in a large number of individuals and its limited antibacterial activity. However, it is an important ingredient in animal feeds. Because feeding levels are quite low, detectable amounts usually are not present in animal tissues. The main public health concern is environmental. Several investigators have reported resistant staphylococci in human attendants working in areas where penicillin was used. In addition, animals appeared to be carriers of penicillin-resistant organisms at a higher percentage than expected (17).

It is widely accepted that the effect of antibiotics upon growth is initiated by modification of the enteric flora. The available documented opinion is that the mode of antibiotic action as a growth stimulant is multifaceted and that alteration of enteric flora is not a complete explanation.

Antibiotics in Crop Protection

In a recent review Goodman (8) listed 25 bacterial and 50 fungal diseases of plants that are amenable to antibiotics for treatment or prevention. At present, only three antibiotics—streptomycin, griseoful-

vin and cycloheximide—have gained wide acceptance in inhibiting plant diseases.

The fundamental advantage of antibiotics over previous methods of plant disease control has been that antibiotics are systemic in their action. Antibiotics not only prevent plant disease but they can also eradicate disease by virtue of their ability to act systemically and be translocated.

Research findings show that the use of streptomycin in plant disease control is not a general hazard for the agricultural worker. Skin testing revealed that workers regularly exposed to the agricultural dosage forms do not develop hypersensitivity to streptomycin more frequently than a randomly selected group.

Streptomycin concentration in agricultural form varies from 15 percent to 30 percent pure; however, in medical usage streptomycin is more than 95 percent pure. Thus, the agricultural worker never encounters the pure crystalline antibiotic. It would seem, therefore, that daily subtle contact with concentrated streptomycin, such as a nurse receives in administering the drug to tuberculosis patients, induces a greater degree of hypersensitivity than massive contact with diluted antibiotic 3 or 4 times per year.

The problem of cycloheximide is somewhat different. This antibiotic is quite toxic and is so labelled by its manufacturers. Thus, while reactions to this drug used in plant disease control are rare, the potential hazard exists.

Antibiotics in Meat Preservation

Rather remarkable preservation powers have been demonstrated in the use of tetracycline antibiotics applied to red meats, fish, and poultry. As many as 20 antibiotics have been evaluated as preservatives but oxytetracycline and chlortetracycline proved most effective.

In all cases of tetracycline preservation of meat, it was apparent that some low-level residue reached the consumer. The residual level in raw meat ranged from 1 to 4 p.p.m. Following cooking, residue decreased but there was still detectable residue regardless if the meat had been cooked rare, medium, or well done. The residue was almost always less than 1.0 p.p.m. (5).

Ayers (2), among others, has shown that tetracyclines were the antibiotics of choice in preserving poultry. Dipping in antibiotic solution appeared to

be the preferred method. When the concentration of dipping solution was limited to 55 p.p.m., the residue level on the bird was less than 7 p.p.m. and all of this appeared to be destroyed by cooking.

Reviewing the literature pertinent to the use of antibiotics in the preservation of fish, Shewan (15) stated that the tetracyclines probably were most efficient in controlling spoilage in fish and seafood. Application of tetracyclines in the form of ice or dipping fillets in antibiotic solution was highly effective in increasing storage ability. However, tetracycline residues of about 1.0–5.0 p.p.m. were usually found in fish treated in this manner.

To date, experimental results suggesting that antibiotics can be used effectively for the preservation of red meat, fish, and poultry have not been readily accepted by regulatory agencies of governments because of unanswered public health questions. Our own Government proposed in the Federal Register of August 23, 1966, to rescind tolerances of residues of chlortetracycline and oxytetracycline previously approved for use in raw poultry, fish, and shellfish.

IMPLICATIONS AND RESEARCH NEEDS

Antibiotics are being widely used as growth promotants in animal feeds, prophylactically and therapeutically in the treatment of diseases of plants and animals, and to a lesser extent as preservatives for food. No doubt some residues have appeared in human foods. However, inhibitory substances, including antibiotics, may also appear in foods from other sources. They may occur naturally in foods as has been noted with garlic, onion, horseradish, banana, and other foods, or they may be produced in a food during its manufacture. Examples of the latter are certain fermented milks and cheeses. Many antibiotics are continually being produced in the soil by naturally occurring micro-organisms; nevertheless, the role of these antibiotics in modifying the ecology of the soil microbial population is still open to question.

Most of the technological innovations, whether concerned with industrial, agricultural or medical practices, are bound to upset the ecological adaptation. Nature is never in a static equilibrium because the interrelationships between its physical and biological components are endlessly changing. Man's survival, let alone growth of his complex societies, implies that he will continue to exploit and, therefore, upset adaptation. The real problem,

therefore, is not how to maintain the balance of nature, but rather how to change it in such a manner that the overall result is favorable for the human and animal species.

Every effort should be made, of course, to determine beforehand the potential dangers of technological innovations. But it would be unrealistic to believe that all these dangers can be recognized or avoided. However, there are certain ecological principles which must be observed if we expect to continue to use antibiotics and drugs as effective weapons in controlling disease.

First, certain antibiotics and drugs should not be used routinely, but only when needed to halt an outbreak of disease, and they should not have a residual effect but should break down into harmless substances and disappear from the environment. Under these conditions, antibiotics would be absent from the environment most of the time; there would not be a selective pressure for the micro-organisms to evolve resistant strains, and the environment would not favor the presence of huge populations of resistant pathogens. Also, the problem of antibiotic residues in foods would be avoided and premises would not be contaminated.

Second, the antibiotic or drug should be as highly specific as possible for the particular etiological agent under attack. This specificity would preserve the indigenous flora and avoid situations where certain pathogens are made more, rather than less, abundant because the drug was more effective in eliminating competitors than in reducing specific pathogens. Specificity would help avoid the difficulty of suppressing one pathogen to have it replaced by another as a result of eliminating competitive microflora.

If the routine use of broad spectrum antibiotics is necessary for medical and agricultural purposes, then it may be desirable to replace (colonize) the disturbed indigenous flora with non-pathogens or less pathogenic agents following therapy or preventive treatment. This procedure has been found of value in reducing or eliminating certain antibiotic resistant bacteria dominating a particular environment. It has been demonstrated that, when the intestinal contents of normal animals were fed to animals in which the intestinal flora had been altered by the use of antimicrobial agents, such feeding restored the so-called microbial balance and enhanced the disease resistance of the altered ani-

mals. Unfortunately, the microbial species involved in the beneficial effect have not yet been identified.

Research must be conducted to answer conclusively whether or not antibiotics used as feed or food additives or as crop protectants are contributing to the development of antibiotic-resistant disease agents.

If this is true, procedures will need to be established to provide effective antibiotic action without inducing resistant flora that might jeopardize the subsequent use of the antibiotics as a chemotherapeutic agent.

All antibiotics, and all drugs for that matter, introduced into medicine and agriculture during the past several decades are now known to cause severe toxic reactions under certain circumstances. Thus, the problem is far more complex than ruling out the use of potentially toxic substances.

Instead, in granting permission for use, the possible advantages must be weighed against the possible disadvantages in order to justify taking risks with human and animal life.

Controversy over the practice of routinely using antibiotics for non-medical purposes including antibiotics in animal feed will continue until research provides more evidence for basing valid judgments.

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Paper Mill Waste Water—Its Effects on the Soil

With the development of pulp and paper mills in the South, one of the problems which confronted the industry was the disposal of tremendous volumes of waste water. Processing 1 ton of newsprint paper requires from 8,000 to 12,000 gallons of water. As this large volume of water leaves the mill system it carries with it dissolved solids, such as chlorides and sulfates of sodium and calcium, and varying amounts of suspended organic material.

Waste water disposal generally has not been a difficult problem for mills located on large streams or near large bodies of water. However, for mills located on small streams close to agricultural areas, the problem of waste water disposal has been extremely important.

Farmers with fields and pastures adjacent to and along Bodcau Bayou in Bossier Parish, La., were making claims for damages to cattle, crops, and soils from papermill waste water that was discharged into the bayou. In 1948, International Paper Co. and Louisiana State University entered into an agreement to establish experiments to determine the validity of the farmers' claims for damages from flooding of land with waste water that had been discharged into Bodcau Bayou. The experiments established in 1948 and continued through 1956 showed that flooding or some excessive irrigation of the soil with papermill waste water did little or no damage to soil, cattle, or crops in most cases. It was observed that the controlled use of the waste water could be beneficial to the growth of crops.

In 1955, the experimental program was changed so that the beneficial effects as well as the harmful effects from the use of papermill waste water for irrigation of various crops could be determined.

A second and very important phase of the program was to determine the effects from prolonged use of waste water on the physical and chemical properties of the soil. Some of the experimental plots received applications of waste water from 1952 through 1964.

Corn in rotation was greatly benefited from the use of papermill waste water for supplemental irrigation. The yield with waste water was 92 bushels per acre; with fresh well water it was 94 bushels, and without irrigation it was 65 bushels per acre for the 8-year period. The effects of the use of the waste water on the soil showed no increases in pH, exchangeable sodium, or soluble salts.

The experiment using papermill waste water for the irrigation of rice indicated that waste water could be used to irrigate rice without harmful effects. The rice irrigated with the waste water yielded 63 bushels per acre, while the rice irrigated with the fresh well water produced 62 bushels.

A high yield of Coastal Bermudagrass, 8.7 tons of hay per acre, was obtained from plots irrigated with papermill waste water. There were small increases in pH and also in the soluble and exchangeable sodium in the surface and subsurface layers from irrigation with the waste water.

In an experiment where corn was grown continuously for a 9-year period, very high yields for the Acadia very fine sandy loam soil were obtained. The plots irrigated with papermill waste water produced 90.1 bushels of corn per acre and the nonirrigated plots produced 69.5.

From: *Bulletin No. 604*, Louisiana Agricultural Experiment Station, December, 1965



RESEARCH NEEDS FOR CONTROLLING SOIL POLLUTION

L. R. WEBBER AND D. E. ELRICK

Just a generation ago Hugh Hammond Bennett capitalized dramatically on soil erosion, drought, and poverty in America and contributed significantly to the realization of the hazards of soil deterioration. Today the productive capacity of some soils is threatened by pollution from domestic and industrial waste disposal practices, a rapidly changing agricultural technology requiring a greater use of agricultural chemicals, and agricultural wastes from raising livestock under confined conditions. There is every reason to expect the volume of wastes to increase and that more and varied wastes will ultimately be disposed in or on soil.

As of now, soil pollution¹ is not widespread but many scientists are concerned about the slow, persistent build-up of toxic compounds in soil. This concern is natural: soil is an essential part of the food chain of humans, animals, and plants.

This article reviews the physical, chemical, and biological properties of soil that influence the adsorption, degradation, and movement of potential pollutants. An attempt is made to indicate areas of productive research in controlling soil pollution and in the disposal of wastes in or on soil.

¹ A soil pollutant is any substance which, when added to the soil, impairs the yield or quality of farm products, affects the health of animals or humans, or which may contribute to subsequent air or water pollution.

Most of the material in this article was originally written as a background paper in preparation for the "National Conference on Pollution and Our Environment" organized by the Canadian Council of Resource Ministers. The conference was held in Montreal from October 31 to November 4, 1966.

SOIL PROPERTIES AND POLLUTANT BEHAVIOR

A soil is a heterogeneous mass as variable in physical and chemical composition as the igneous, metamorphic, and sedimentary rocks that were originally the parent soil materials. Since deglaciation, 10 to 15 thousand years ago, the parent soil material has undergone soil-forming processes that have gradually differentiated this material into layers or horizons uniquely different from the parent soil material. Collectively these horizons constitute a soil profile—a small three-dimensional section from the soil surface down through all developed horizons into the underlying soil materials. It is this portion of the unconsolidated material, varying greatly in depth, that constitutes a soil.



FIGURE 5.—An aerial view of the sedimentation ponds and lagoons of Beardmore and Company, leather tanners, Acton, Ontario, Canada. This photo was taken in early spring when the company was disposing of several winter months' accumulation of waste liquids by sprinkler irrigation (whitish circles in the lower right). Irrigation is continued throughout the growing season on grass sward. This practice contributes significantly to re-charge of the groundwater supply. (Photo supplied by courtesy of Lockwood Survey Corporation, Toronto, Ontario.)

Soil profiles may be described, grouped, and classified into various categories. The soil map is the most detailed and accurate soil inventory available and, although developed primarily for agricultural purposes, can nevertheless be useful when one is confronted with suburban and rural pollution problems (18).²

PHYSICAL PROPERTIES

Soil Solids

The most important soil solids (the skeletal matrix) are products of rock weathering (silica, silicates,

oxides of iron and manganese, carbonates, phosphates, and many others in small amounts). Normally, organic matter represents less than 10 percent by weight, but because of its colloidal nature, it is the site of many physical and chemical reactions.

Aggregation of the fine silt, clay, and organic matter occurs in loams and fine textured soils; there may be little or no aggregation in sandy soils. Aggregates give a soil a unique structural form. The internal geometry of a soil mass is determined largely by these structural units. If the clay and silt particles were separate grains and were dispersed, soils would become extremely hard and compact. Ex-

² Italic numbers in parentheses refer to Literature Cited, p. 20.

cessive tillage and heavy application of chemicals, particularly sodium compounds, tend to destroy soil aggregation and induce compaction.

Soil Porosity and Aeration

The porous matrix of a soil is determined by the structure and arrangement of the soil solids. Individual pores vary in size and shape; they may be continuous or blocked. Soil pores occur inside and among individual soil aggregates. The total pore space of a soil depends upon the structure or arrangement of the soil particles and can vary from 35 to 65 percent of the total soil volume. The pore space is filled with water containing dissolved substances, water vapor, volatile chemical substances, and gases. Movement in the liquid and vapor phases takes place by a combination of diffusion and mass flow.

The pore space available to the gaseous phase depends upon the amount of water present. The volume occupied by large pores determines the extent of soil aeration, a significant factor in the degradation of pollutants.

Soil Water

Only a portion of the precipitation reaching the earth's surface infiltrates the soil to become part of the soil-water system. Interception by the plant canopy and surface runoff restrict the amount of water entering the soil. Groundwater recharge and evaporation at the soil surface reduce the amount of water retained by the soil.

Water which finds its way into the soil may be "stored" locally or may move, depending upon the energy with which the water is retained in various parts of the soil. In general, the size of the soil pores determines the quantity of water a soil will hold against pressures tending to remove it. The relationship between the soil water content and pressure (commonly called the soil-water characteristic) is obtained experimentally (fig. 1).

Harris³ has shown that the water content of a soil has an important influence on the toxicity of insecticides. Behavior in different soils was compared by plotting LD₅₀ (dosage lethal to 50 percent) as a function of soil water or soil water tension. As shown in Fig. 2, DDT and parathion in mineral

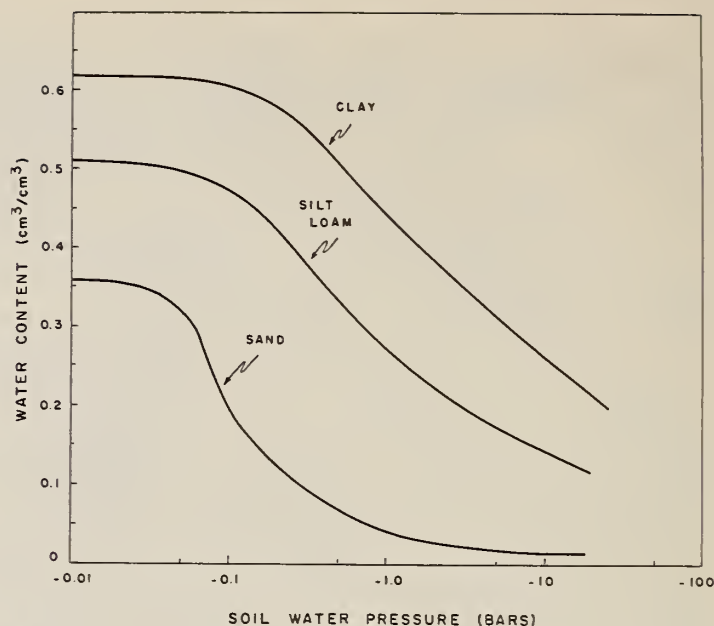


FIGURE 1.—Soil-water characteristic curves for three soils having different textures.

soils are least toxic at zero moisture and most toxic at water contents equivalent to 1.0 bar or less tension. In a muck soil the toxicity of DDT increased and parathion decreased with increasing water content. In general, as the organic matter content of soil increased, the effectiveness of the insecticide decreased for a given soil moisture tension value. These results agree with other data which showed that adsorption and biodegradation of herbicides were positively correlated with soil organic-matter content.

Movement of Water and Chemical Substances

Movement of water in the saturated or unsaturated phase takes place when there are differences in the pressure potential of the soil water between points in the soil system. The principles involved in this movement have been reviewed by Elrick (7). The unsaturated conductivity, a parameter which must be determined experimentally, reflects the ability of a soil to transmit water at a specified water content (Fig. 3). Such information as in Figures 1 and 3 comprises the microhydrologic properties of a soil and is used to predict water movement patterns; for example, infiltration, drainage, leaching, evaporation, movement to plant roots, etc.

Within a porous medium, the movement of chemical substances takes place by diffusion or convection in either the liquid or vapor phases. Chemical re-

³ Personal communication with C.R. Harris, Entomology Laboratory, Chatham, Ontario.

actions such as adsorption, fixation, precipitation, and breakdown or decay of the chemical, influence the transport process in a variety of ways. Change in concentration of a chemical with a small volume of soil depends upon diffusion, convection, and reaction.

Two mechanisms are responsible for the movement of chemical substances: (1) diffusive movement because of variations in concentration with position in the soil; and (2) convective (mass) flow of water and soil air.

Any or all of the previously mentioned reactions can take place and thus alter the movement pattern. With the majority of chemical substances, it is expected that transfer will take place mostly in the liquid phase, although vapor phase transfer will become more important at the lower water content and with the more volatile substances.

The reactions discussed previously can take place within the soil and may depend upon concentration, position, and time. In all cases it is necessary to

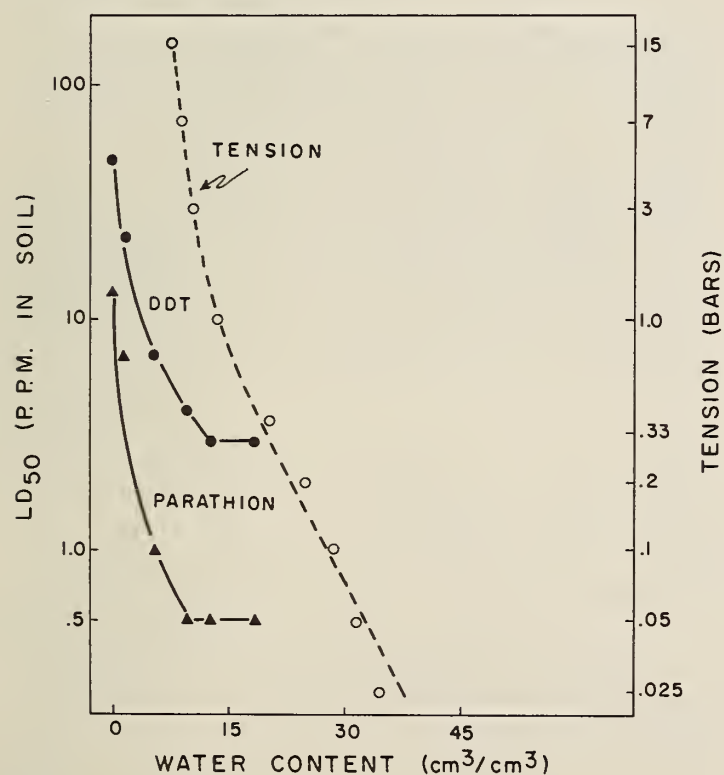


FIGURE 2.—Influence of soil water on the toxicity of DDT and parathion in Beverly sand (test insects—first instar cricket nymphs). The dashed line relates the soil-water tension (negative pressure) as shown on the right-hand ordinate to the water content. Adapted from 1964 data from the Entomology Laboratory, Chatham, Ontario. (Personal Communication.)

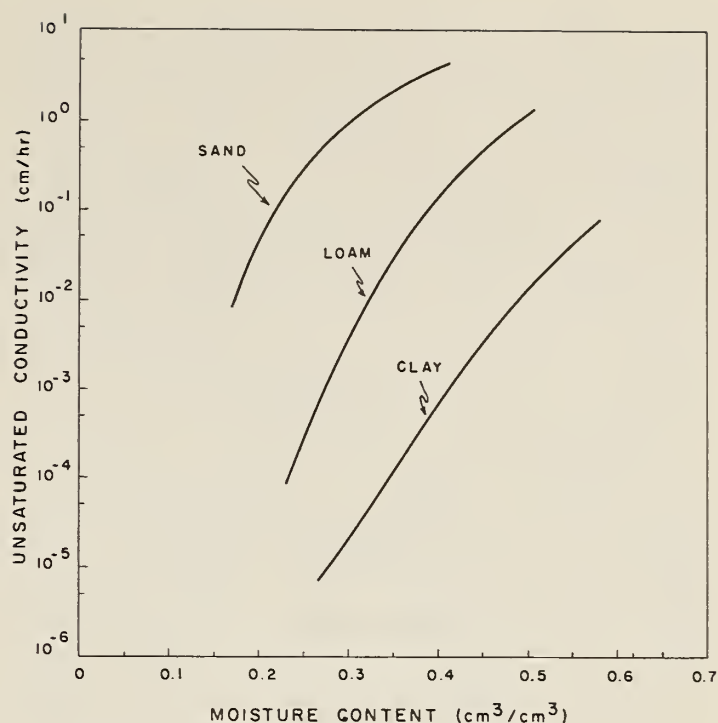


FIGURE 3.—Capillary conductivity as a function of volumetric moisture content for three soils having different textures.

know the relationship between the concentration of the chemical in the solution (or perhaps vapor) phase and that in the reacted phase.

Apparatus developed for studying water movement in soils has been modified so that the movement of chemicals and reactions with the soil can be studied (8). Preliminary data on the movement of Cl^- and the Ca salt of 2, 4-D through an unsaturated, 15-cm column of Honeywood silt loam are shown in Figure 4. The Cl^- was used to follow the water movement pattern as it is adsorbed in negligible amounts by soil. The solid lines in Fig. 4 were calculated by using a mathematical model similar to that developed for column chromatography.

CHEMICAL PROPERTIES

A knowledge of the soil properties affecting the behavior of applied soil chemicals is of prime importance in developing new chemicals or in studying the fate of existing compounds.

Cation Exchange

In the pollution of soil by inorganic and organic cations, the principle of cation exchange is the dom-

inant chemical property. To understand the exchange process, research has been directed towards colloidal fraction. The principal exchange cations in soils are calcium, magnesium, potassium, sodium, aluminum, and hydrogen. Under specific situations, the exchange of cations from the solution to the exchange site on a colloid is a mass action effect. In other situations a complex equilibrium exists and selective or preferential adsorption takes place.

Most cation exchange reactions in soils are reversible; irreversibility is usually associated with the strong attachment of certain cations in specific exchange positions. Potassium and ammonium ions are firmly held in interlayer positions of illite and vermiculite while calcium, sodium, magnesium, and lithium ions are readily exchanged from the same position. In many soils, the total amount of bases liable to be adsorbed far exceeds the actual adsorption. Quantitative data on some important chemical properties of clay minerals and organic matter are given in Table 1.

Inorganic Colloids (Clay Minerals)

Clay minerals are charged negatively because of the isomorphous substitution of ions; for example, Si^{4+} by Al^{3+} -ions. Negative charges may also be caused by the ionization of exposed AlOH - and SiOH -groups. The contribution of ionization to exchange in kaolinite is important but isomorphous substitution is the dominant source of negative charges in other clays.

Montmorillonite possesses an expanding type of crystal structure that swells and shrinks. Illite and

kaolinite are non-expanding lattice structures. The restricted entry of water in the illite structure accounts for the lower exchange capacity.

Ensminger and Gieseking (9) demonstrated the strong attraction of a large organic cation, gelatin, on the inorganic soil fraction. These authors also noted that protein-montmorillonite complexes showed only a slight tendency to biodegradation. Pinck *et al.* (19) have shown that if the clay structure is greatly expanded by the adsorption of organic molecules decomposition proceeds readily.

Organic Colloids

Soil organic matter presents an enormous surface area (Table 1). Partially decayed cellulose, lignin, and their residues have an accessible internal surface. The molecular structure of organic matter is more favorable to accommodate organic molecules than the aluminum-silicon surface of inorganic clay minerals (11).

Organic matter contributes significantly to cation exchange (Table 1). After examining the cation exchange capacity, Black (4) concluded that 30 to 60 percent of the exchange capacities of soil was attributed to organic matter. He reported that 54 percent of the exchange positions in organic matter were in the carboxyl groups, 36 percent in phenolic and enolic hydroxyl groups, and 10 percent in the amide group.

Many organic compounds, when added to soil, are not necessarily resistant to decomposition, but remain in the soil because of a low level of chemical and biological degradation.

TABLE 1.—*Selected physical properties of soil constituents*

[Adapted from (2)]

Soil constituent	Cation exchange capacity	Surface area
	<i>meq. per 100 g.</i>	<i>m.² per g.</i>
Organic matter.....	200-400	500-800
Vermiculite.....	100-150	600-800
Montmorillonite.....	80-150	600-800
Illite.....	10-40	65-100
Kaolinite..	3-15	7-30

Adsorption Mechanisms

Bailey and White (2) reviewed the literature pertaining to the adsorption and desorption of organic chemicals (pesticides) by soil colloids. The mechanisms by which specific compounds are held in soil may explain in part the fate of applied chemicals, particularly pesticides.

Van der Waal adsorption is due principally to orientation or dipole-dipole interactions, polarization or induced dipole interactions. This type of adsorption results in low heats of adsorption and weak binding strength. Although several monolayers may be involved, only the first layer is chemically bonded; all other layers are physically adsorbed.

Adsorption may also be due to coulombic forces between the adsorbent and adsorbate, and results in high heats of adsorption and high bonding strength.

Montmorillonite and vermiculite have a high cation exchange capacity, large surface area (Table 1) and great capacities for adsorption. Other clay minerals such as illite and kaolinite do not have a large adsorption capacity.

Sheets *et al.* (20) correlated the LD₅₀-value for simazine with four soil properties: organic matter, clay content, cation exchange capacity, and pH. Organic matter was the best single predictor, accounting for 77 percent of the variation; 87 percent of the variation was accounted for when all 4 soil properties were used in a multiple correlation.

Bailey and White (2) pointed out that adsorption was influenced by other properties of a chemical, such as:

(1) Nature of the functional group, carboxyl and aluminum complexes; hydrogen bonding between an amino group and the clay surface.

(2) Charge carried and the pH of the chemical upon dissociation.

(3) Relationship between pH and solubility of the chemical.

(4) Nature of the inorganic cation on the exchange complex of the soil.

BIOLOGICAL PROPERTIES

Micro-organisms are not distributed uniformly throughout the various soil layers; they occur most abundantly in the surface layer where the conditions

for growth—warmth, moisture, food supply, and organic matter—are most favorable. In general, the nutritional requirements of micro-organisms are similar to those of the higher plants. They require carbon, hydrogen, oxygen, nitrogen, and many other elements. Their dry weight ranges from 50 to 1,300 pounds per acre of surface soil and these micro-organisms will contain up to 130 pounds of nitrogen per acre.

Bacteria, actinomycetes, and fungi are potent agents of decomposition. They are indispensable: (1) in the mineralization of plant and animal residues, (2) in increasing the availability to higher plants of minerals in inorganic combinations, and (3) as an essential activity in the nitrogen cycle. Microbiological activity contributes significantly to the recycling of many chemical elements and the formation of a stable soil structure.

Biodegradation of Applied Chemicals

Significant positive correlations exist between the rate of herbicide disappearance and the extent to which the soil conditions favor bacterial growth (1). Proof of the dominating role of bacteria in the detoxication process is established when the responsible organism is isolated and grown in pure culture by using the applied chemicals as the sole source of carbon.

Audus (1) has demonstrated that specific genera are capable of metabolizing certain chlorinated organic compounds; simazine was decomposed only by fungi and actinomycetes. The rate of biodegradation increased in soils rich in organic matter.

Biological Pollution

There is the danger of biological contamination of water supplies by bacteria and viruses when domestic wastes are disposed in soil. Such contamination is often determined by the viability of the organism in the soil, its interaction with the soil and the nature of the transport. This problem is of continuing interest even though a large number of studies on bacterial transport in soil and other porous media have been conducted. The reason for the interest is twofold: (1) a complete lack of information on the fate of disease-causing virus in soils, and (2) the outbreak of disease caused by pollution of ground water supplies which have been contaminated from sources that appear to be a safe distance away.

A recent review of the biological contamination of ground water (16) cites a number of examples in which bacteria and virus have moved from several inches up to 800 feet. Such movements have resulted in outbreaks of hepatitis, dysentery, typhoid, and polio.

Even now there is not an established relationship between soil characteristics, water movement, and micro-organism movement. Attempts are being made to relate survival and adsorption of virus in soil to the movement that may occur. Eliassen, Kruger, and Frewry (6) have applied the analysis of Hiester and Vermeulen (12) to bacterial virus movement in various types of soils. From such studies, by using radioactive virus, it is hoped that some reliable basis for prediction of movement can be formulated.

It is readily apparent that organism survival in the soil becomes an important factor as it relates to movement and contamination. Here again it is not possible to predict the survival time of an organism based on soil characteristics. *E. coli* and *A. aerogenes* have survived for periods up to 4 years (14). *S. typhosa* was found by Mallmann and Litsky (15) to die out in less than 48 days; the longest survival occurred in soils of high organic content. Such conditions would occur where wastes from septic tanks, cesspools, or untreated sewage are applied to the soil.

METHODS OF CONTROL

There is little doubt that control measures must be based on a thorough understanding of the behavior of potential pollutants not only in the soil but throughout the total environment.

Applied Soil Chemicals

An ever-increasing number and variety of chemicals are applied directly to the soil or come in contact with the soil surface by wash from foliage, by leaf fall, and by other means. These chemicals are usually not considered as pollutants but are classified as insecticides, herbicides, rodenticides, fertilizers, etc. However, the combination of high rates of application, widespread use of compounds that are toxic to wildlife and man, and the use of persistent chemicals that resist microbial attack and chemical breakdown can quickly add up to a widespread problem.

Pesticidal residues can probably best be controlled through registration procedures. For example, when traces of dieldrin and aldrin were found in the fat of animals that had grazed on forage treated with these chemicals for grasshopper control, the products were removed from the market for this use (17). A new product, Sevin,⁴ which does not have these residue problems, was then developed. Also, the British Columbia fruit industry (21) eliminated arsenical sprays in 1938 when trace amounts of arsenic were found in apples.

At present there is considerable controversy on the effects of nitrates in water supplies for animals and man. Severe cases of water supplies contaminated with nitrate have contributed to, or been entirely responsible for, the poisoning of animals. Human health has also been jeopardized, and in some cases lives have been lost due to high-nitrate waters (23). Using experimental techniques similar to that described for the 2,4-D studies (8), Erh *et al.*⁵ have shown that ammonium nitrogen, when added to unsaturated soil, is rapidly converted to the nitrate form; the nitrates showed little adsorptive effects with the soil and, to a first approximation, moved with the water. Thus nitrogen can be rapidly leached through the soil. More research is needed to evaluate the effect of nitrate fertilizers, animal manure, and natural sources on nitrate accumulation in the groundwater supplies.

Waste Disposal

The soil is not only a medium for plant growth but is also a potential medium for the disposal of wastes. For example, a significant proportion of this country's population depends on waste disposal through soil absorption in septic tank leaching fields. A knowledge of drainage conditions and the water-transmitting properties of a soil is essential for selecting suitable locations and for proper design for septic tank systems. The rate at which a soil absorbs the effluent is critical to the operation of the

⁴ Trade names are used in this publication solely for the purpose of providing specific information. Mention of trade names does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture over other products not mentioned.

⁵ Erh, K.T., D.E. Elrick, R.L. Thomas and C.T. Corke. Dynamics of nitrification in soils using a miscible displacement technique. Presented in August, 1966 to the American Society of Agronomy Annual Meeting at Stillwater, Oklahoma.

disposal system. If the effluent drains through the soil too rapidly, it may travel unfiltered into wells or surface-water supplies and contaminate them with various types of disease-bearing organisms. As a specific example, it is probable that the 1964 outbreak of infectious hepatitis at the Yarker Public School in Ontario was due to contamination of the well water by the school's septic tank system. Chemical and bacteriological tests by the Ontario Water Resources Commission indicated that leakage or seepage from the school's sewage disposal system was polluting the school water supply. Soils in this area are shallow, and rock occurs at or near the surface in many places.

The disposal of industrial wastes on or in soils

after a minimum of treatment has been an objective for a long time. The goals have been to avoid stream and groundwater pollution and minimize objectionable odors. Four general methods for the land disposal of wastes are used: (1) impounding lagoons, (2) absorption beds, (3) ridge and furrow irrigation, and (4) sprinkler irrigation. An example of successful disposal by the use of sprinkler irrigation is shown in fig. 5.

Lagooning and absorption beds have been operated successfully for some time where provision has been made for adequate capacity and thorough aeration (either natural or artificial). Monitoring and control of the biochemical oxygen demand (BOD) of the effluent are essential as the effluent is

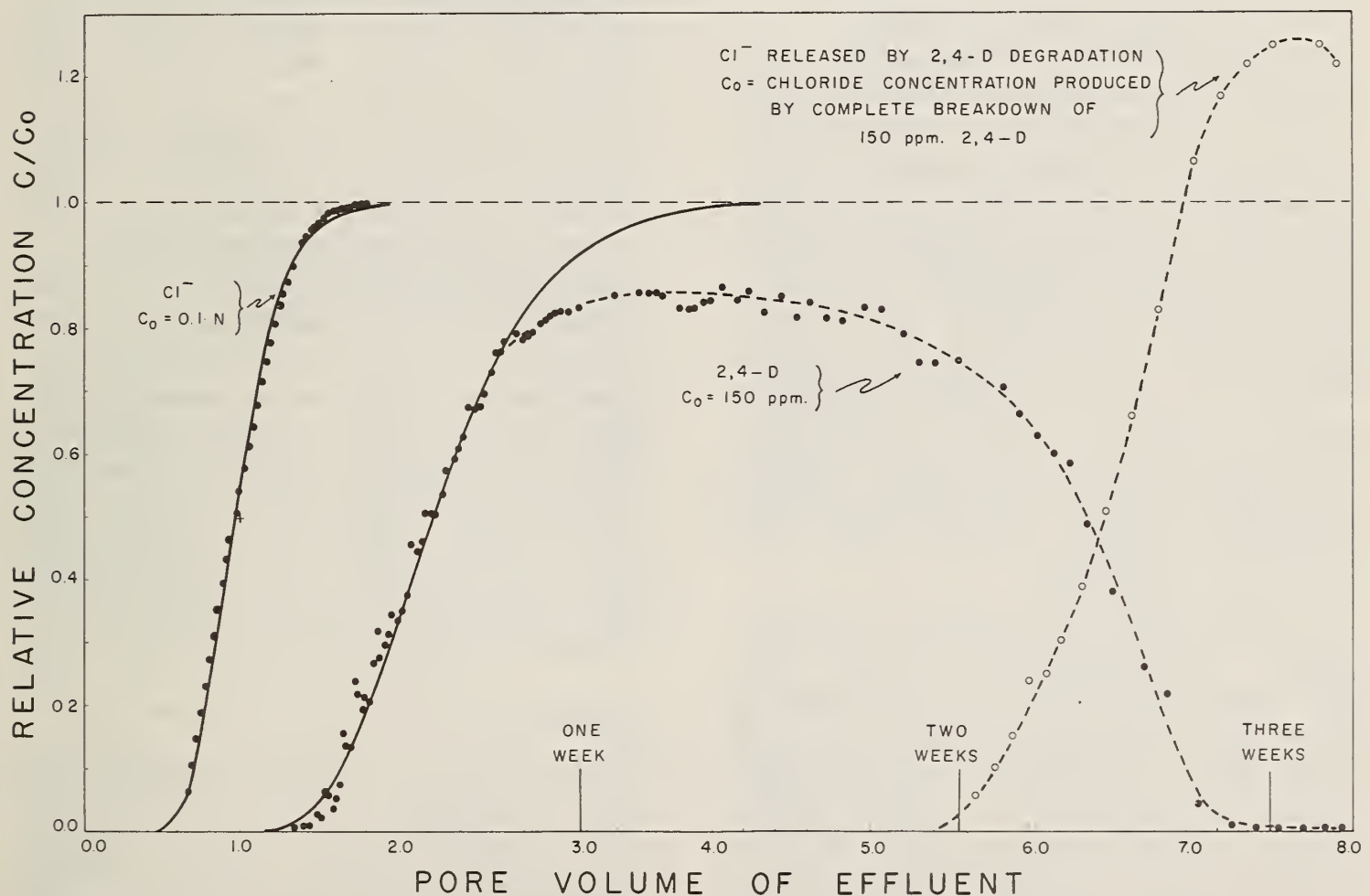


FIGURE 4.—Breakthrough curves for Cl^- and for 2,4-D from Honeywood silt loam. The Cl^- curve on the right-hand side is that produced from the breakdown of 2,4-D. The ratio of the concentration of the solution coming out of the soil column, C , to the concentration entering the column, C_0 , is plotted against the amount of solution that has passed through the column. Time, in weeks, is also shown on the abscissa scale. The average pore velocity was 0.42 cm./hr. One pore volume is the volume of soil solution contained by the soil column under the condition of the experiment. Solid lines are theoretical curves of best fit and the dashed lines are drawn through the data points. The soil pore space was 84 percent filled with solution.

discharged to streams, enters the groundwater supply, or is spread on the surface. Ridge and furrow methods require a permeable soil to permit absorption and reduce the hazards of ponding, clogging soil pores, and foul odors.

In Ontario sodium wastes from seasonal cannery operations when spray irrigated on a fine-textured soil increased the exchangeable sodium in all soil horizons, but the concentration of exchangeable sodium and the electrical conductivity of the soil extract did not approach values that would interfere with crop production (3, 22). In the design of a spray program, particular use is made of such soil properties as infiltration, range of available water, content of clay and organic matter. These soil properties influence rate and frequency of waste applications. Maximum evapotranspiration of dense plant cover is encouraged by the selection of plant cover and by management in order to keep the crop in a vegetative stage of growth.

In Pennsylvania (13) chlorinated effluent from the University's sewage treatment plant was applied to field crops and forest areas through a sprinkler irrigation system. During the period April to November 1964, 66 inches of effluent were applied to a soil. The application of the effluent resulted in substantial increases in the yield of hay and corn; wheat was practically unaffected in yield but the protein content was increased. The renovation efficiency of the effluent was about 97 percent in removing detergents and better than 99 percent in removing phosphorus. It was estimated that nearly 1½ million gallons of water per acre reached the groundwater reservoir. This waste water renovation project is continuing.

RESEARCH AND TECHNOLOGICAL NEEDS

The ultimate fate of chemical and biological substances when added to the soil depends upon the physical, chemical and biological environment within the soil. Because soil, water, and air pollution processes most often are interrelated, the overall behavior in the total environment of potential pollutants must be understood before adequate control measures can be developed.

At present, pollution is for the most part below levels that have been demonstrated to cause disease or death. However, the number of documented instances where pollution has occurred continues to grow. There is ample evidence that some toxic

pollutants are accumulating in soils. Ignorance in many phases of pollution limits our ability to deal effectively with the problem. Quick answers must often be found before the full effects of environmental changes produced by pollution are known.

If we assume that it is inevitable that some potential contaminants will be applied to, or in other ways come in contact with, our soils, then our future research should include the following areas of study.

Benchmark Studies

Benchmark studies on soils throughout the country should be established to provide background information on the physical, chemical, and biological status of our soils. This information is necessary to establish changes that may be brought about by pollutants. It is also needed as a basis for design criteria. For example, it is important to know the changes in radioactivity of plant tissue that have been brought about by radioactive fallout from atmospheric nuclear tests. Gorham (10) reported that plants of low mineral content from acid, infertile soils exhibited unusually high levels of fallout radioactivity. Radioactivity analysis of the organic litter from pine trees sampled in the spring of 1962 was about 30 times the natural beta-activity before worldwide thermonuclear fallout; however, samples of mineral soils showed only relatively slight differences in ash activity. A case could be stated for the lead content of soils. Contamination from automobile exhausts in soils near highways and direct contamination of vegetables and crops in these areas can raise the lead content of plant tissue to excessively high levels. Thus, background levels of potential pollutants should be determined for representative soils by establishing benchmark studies in conjunction with the soil survey program.

Permissible Levels of Pollutants in Soil

Permissible levels of potential pollutants in soils should be established. In order to determine these levels with contaminants that are absorbed by plant tissue, there must be further research in relating concentrations in plant tissue to concentrations in the soil. Once toxic levels are established within plant tissue, then permissible levels can be established for soils. Permissible levels should also be established for contaminants that are mobile within the soil and may possibly contaminate groundwater supplies. The influence of various soil properties

and soil types on these permissible levels should also be examined.

Pollutant Behavior in Soil

There should be expanded research on the overall behavior of pollutants in soils, and in turn on the effects of these pollutants on soils under various environmental conditions. Research on analytical and biological procedures for the analysis of potential pollutants must also be expanded before many informative studies can be undertaken. In particular, the persistence, movement, and rate of degradation of potential pollutants under various soil and environmental conditions should be examined. Some soil properties of importance include pH, water content and water flow properties, exchangeable ions, amount and type of clay, amount and type of organic matter, and microbiological characteristics. Temperature and precipitation are important environmental conditions affecting pollutant behavior.

Additional Needs

As discussed previously, pollutants can arise from a number of sources. Many industries are concerned about pollution but are confronted with difficult disposal problems. Often within the plant itself, pollutants must be separated from large volumes of effluent and then concentrated, transported, and ultimately disposed. Some soils are, in essence, used as vaults to contain refractory waste, and other soils can be used to degrade and dilute pollutants to permissible levels. As examples, radioactive wastes are often stored in vaults imbedded in the soil and cannery wastes are degraded and diluted to permissible levels by surface application to soils.

When large volumes of water are spread on permeable soils, the function of the soil is to adsorb some chemicals, biodegrade the organic compounds, and deliver clean water to the groundwater supply. Research should be expanded to evaluate soils as renovating agents and to investigate techniques for enhancing biodegradation (furrows, terraces, sprinkler use, forced aeration, etc.). In general, information should be available on (1) the amount of a particular waste that a specific soil type can degrade, (2) the most effective crop cover, (3) the quantity of water that can be applied, and (4) the amount

and purity of the water added to the groundwater supply.

Information is required on improving the performance of septic tank leaching fields and the spread of pollutants from sanitary land fills, dumps, and specific cases of accidental pollution. Persistence, movement, and degradation of specific compounds as well as groundwater movement patterns must be understood so that the overall performance can be evaluated. A large proportion of the Canadian population is serviced by septic tank systems; suburban development schemes utilizing septic tank systems require performance standards which should be based on soil properties.

The selection of suitable sanitary land-fill areas must similarly be based on soil and groundwater properties. For example, a study on "Effects of Refuse Dumps on Groundwater Quality" (5) stated: "The values at stake are enormous, both in terms of the storage capacity and concomitant security of the groundwater reservoirs and in terms of the potential land reclaimed for re-use through landfilling. Studies should be designed not just to minimize the hazard, but, if possible, to eliminate completely the risk of exposure of the groundwater to damaging pollution." This report recommended investigations on gas production quantities, observations of gas movement, control of gas movement, leaching studies, monitoring of field moisture, and prevention of pollution.

The direct or indirect application of synthetic chemicals to soils such as pesticides, growth regulators, fertilizers, etc. should be based on criteria other than solely increasing crop production. A 100 percent kill-approach for pesticides and the routine use of chemicals whose fate and persistence are unknown appear as a short-sighted policy. Molecular modifications of compounds affect their overall behavior, including degradability. Industry should develop the ideal pesticide—one that is effective for its specific purpose and will be converted to harmless forms at a rate that will not pollute any aspect of the environment.

Education at all levels is extremely important. A high priority needs to be given to increasing both the number and the training of scientists, engineers, and extension personnel interested in problems related to the control and management of soil, water, and air pollution.

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TROPICAL RICE: The Quest for High Yield

E. A. JACKSON

The immediate task of the tropical rice scientist is to increase yield. Eventually it may be possible to raise the protein content of the grain, and concentrate more on quality generally, but the pressing need at this stage of the world's development is simply to ensure that rice yields are raised to a level that will enable the dense populations of Asia to stay alive.

About one quarter of the world's total cereal production is rice, and over half of it is grown in the tropics—mainly the Asian tropics. Although rice has been cultivated throughout Asia for generations and is the staple food for a large proportion of the population, tropical yields are deplorably low by world standards. National average yields for temperate zone countries, such as Japan, Australia, and those bordering the Mediterranean, range from about 4 to 6 metric tons per hectare. The corresponding figures for tropical countries seldom exceed 2 ton/ha. The average Indian yield is about 1.5, that of Thailand 1.6, and of the Philippines 1.2 ton/ha. Such low productivity is particularly lamentable when one remembers that it is in precisely these tropical regions that the food problem is most acute.

The greater yields in temperate regions can partly be explained by the better water control, land prep-

aration, weed and pest control, and other cultural practices. Furthermore, in the tropics rice is frequently grown as a subsistence crop under conditions of soil and climate that are far from ideal, whereas in temperate countries it is more often grown only where the soil and the degree of water control are adequate. Nevertheless, until quite recently the best yields obtainable at tropical experiment stations were also relatively low and generally less than the average yields of many temperate countries. Thus, even when carefully tended, rice has produced less abundantly in the tropics than in temperate areas. Climatic factors—high temperatures and humidity, short days, and low light intensity in the tropics—are doubtless important, but results of recent research have emphasized the importance of plant type differences between the two zones (1, 12).¹

Japonicas and Indicas

Most rice varieties can be classified loosely into either indica or japonica types. Indica rices are typically those of the tropics. They are tall and weak-stemmed, with a profusion of long, drooping,

¹ Italic numbers in parentheses refer to Literature Cited, p. 26.

pale green leaves. Late maturity, photoperiod sensitivity, and a strong tillering habit are other common features. The grain usually remains dormant for a period following maturity—an important trait in the tropics where high humidity can cause grain to germinate on the panicle before harvest. The yield response of indica varieties to improved cultural practices is generally disappointing. Nitrogen application, for example, often leads to taller and leafier plants but little or no additional grain. It seems probable that these tropical varieties have evolved as a result of selection by generations of farmers who required plants that would thrive under conditions of low fertility, poor water and weed control, and a primitive agricultural system generally.

Japonica varieties, which are typical of the temperate zone, are by contrast short sturdy plants with erect, short, dark-green leaves. They lack grain dormancy and many varieties are photoperiod sensitive. In temperate areas they are high-yielding and responsive in terms of grain yield to nitrogen applications and other improved cultural practices. When grown in the tropics, however, their sensitivity to temperature or day length usually results in early maturity and stunted development. Furthermore, the grain lacks dormancy, and the cooked product is unacceptable to most tropical consumers. For these reasons, introductions of japonica varieties to the tropics have been largely unsuccessful.

A further group of varieties, grown in subtropical areas such as Taiwan and the southern United States, are regarded as indicas but in plant type resemble japonica varieties: they are short, sturdy, and erect, produce high yields, and are responsive to nitrogen.

Since high-yielding rice varieties, whether indicas or japonicas, are of a particular plant type, it became clear that the logical objective was to develop such types for tropical conditions. In the meantime, however, plant physiologists had been studying the growth processes of rice in the tropics and were able not only to define desirable plant characteristics more precisely, but also to offer explanations as to why such characteristics were associated with high grain yields.

Mutual Shading

The photosynthetic rate of any crop is controlled by the concentration of CO_2 in the air and the light

intensity. For a tropical rice crop the CO_2 concentration is probably never a limiting factor. Light intensity, however, is often limiting. Particularly during the monsoon season, clouds obscure the sun and at some growth stages reduce intensity to a level below that required for maximum growth rate. In addition, because of mutual shading of one plant by another, some leaves receive inadequate light for maximum photosynthesis even on days of high light intensity (17).

The deleterious effect of low light intensity reflects, of course, an unfavorable balance between photosynthesis and respiration. In general, the respiratory rate of a crop is proportional to the total weight of plants. As the crop grows, the rate of respiration per unit land area increases. If the increased weight of plant tissue in a growing crop is a reflection of an increased weight of non-photosynthesizing organs, the resulting greater rate of respiration will cause a decrease in dry matter production. Shaded leaves respire just as actively as unshaded ones, but, because they are not assimilating sufficient carbon for their own requirements, they draw supplies from upper leaves and from stored material in the leaf sheaths and culms. Similarly, the respiration of the long internodes of tall varieties results in a substantial loss of carbon without any compensating gain through photosynthesis.

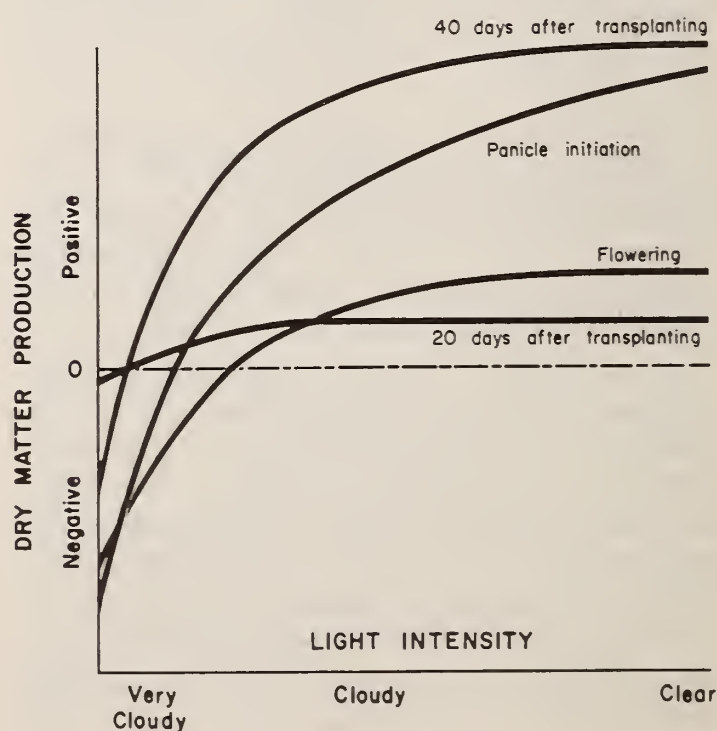


FIGURE 1.—The effect of light intensity on dry-matter production of rice plants at several growth stages. From Tanaka *et al.* (18).

Mutual shading, and light intensity generally, are unimportant in the early growth stages; the leaf canopy is sparse, mutual shading is insignificant, and full photosynthetic capacity is satisfied at fairly low light intensities (17). By the panicle initiation stage, however, the high photosynthetic capacity is realized only at full sunlight, and even slight cloudiness lowers the rate at which carbon is assimilated. At flowering stage, mutual shading has become significant and there is an increased proportion of non-photosynthesizing tissue; on cloudy days the plants actually lose weight (fig. 1) (18). Furthermore, it has been shown in C^{14} studies (14) that of the total carbon in the brown rice at harvest, 80 percent is assimilated after flowering. The importance of high light intensity during late growth stages was confirmed in experiments at The International Rice Research Institute (8). In a study of three varieties planted at monthly intervals over a 2-year period, grain yield was positively correlated with solar radiation received over the last 4–6 weeks before harvest.

The severity of mutual shading is strongly influenced by the plant type and the nature of its response to nitrogen (19). The tall (exceeding 140 cm) tropical indicas, which have a poor grain-yield response to nitrogen, utilize photosynthetic products in vegetative growth rather than as starch in the grain. They grow vigorously in the early growth stages, particularly with adequate nitrogen, but more slowly in the later stages. Their early vigorous vegetative growth in response to nitrogen applications causes crowded conditions in the field, severe mutual shading, and consequently a low grain-yield response to nitrogen. If plants of such varieties are grown under isolated conditions where adequate light is available, the grain-yield response to nitrogen is much greater. The effect of nitrogen application on mutual shading has been measured in an experiment described by Tanaka *et al.* (18). By comparing the grain yields of potted plants located in a crop with those of plants grown in pots in the open, it was shown that, for a tall indica variety, mutual shading caused grain yield to be reduced by 10 percent in the absence of applied nitrogen, but by nearly 50 percent where 100 kg/ha. nitrogen was applied.

The effect of mutual shading is to increase plant height, weaken root development, reduce the proportion of grain to total plant weight, and decrease

nitrogen uptake and the efficiency of its utilization in the plant (19). If mutual shading is prolonged, the shaded leaves lose their photosynthesizing capacity and die (15).

In contrast to the tall indicas, short statured (90–110 cm.), nitrogen-responsive varieties grow slowly during early growth stages and do not utilize added nitrogen to promote excessive early growth. Thus, mutual shading is much less serious.

A further major weakness of tall indica varieties, and one which is also accentuated by nitrogen applications, is their susceptibility to lodging.

The Lodging Problem

The stress of rain and wind, particularly during the wet season when most tropical rice is grown, causes a large proportion of the crop to lodge before it is ready to harvest. Apart from adverse yield effects, a lodged crop is virtually impossible to harvest mechanically. Lodging is thus a major impediment to mechanized rice harvesting in the tropics.

The magnitude of the yield reduction caused by lodging depends on the stage at which lodging occurs. If it occurs before flowering, for example, the loss in yield is much greater than where the crop lodges a few days before harvest. Nevertheless, observations have shown that there is some yield loss even if the crop lodges as late as 10 days before harvest.

In experiments by Jennings and Sornchai (13), in which control plots were prevented from lodging with string supports, grain losses ranged from 50 to 80 percent as a result of lodging. These losses were incurred in the wet season with several tall indicas which lodged before flowering. The effect was much less severe in the dry season, and in this instance it increased with increased nitrogen applications. In the same series of experiments, a japonica variety from Taiwan did not lodge and yielded as well when the plants were supported as when they were not.

Because it disturbs the normal leaf arrangement, lodging interferes with photosynthesis. It also probably restricts the flow of nutrients in the stem (3, 4, 5, 6). The direct effect of early lodging is to increase the proportion of flowers that fail to form grain. In the experiments by Jennings and Sornchai, the increased sterility was proportional to the reduction in grain yield.

Chang (2) has described the plant characteristics important in lodging behavior. From simple mechanical considerations it is obvious that the greatest strain on a culm is near its base, and observations confirm that most of the bending and buckling occurs at the two lowest elongated internodes. Because they derive support from the adjoining nodes, short internodes are generally stronger than long ones. Varieties with short basal internodes are therefore preferred. Internode strength, however, is also an inherent characteristic of the variety and not solely a function of its length.

Short stature is an advantage because of the smaller leverage exerted on the base of the stem.

The leaf sheath helps to strengthen the stem. If the sheath is removed, a smaller force is required to break or bend the internode. The extent to which the sheaths enclose the internodes, and the tightness of their grip on the stems, varies among varieties and helps to determine their lodging resistance.

Erect leaves, because they shed water more easily and thus lessen the chances of the plant becoming top-heavy, are preferred to long drooping ones. Cylindrical culms with thick walls resist lodging better than those that are thin-walled and asymmetrical in cross section. Early maturity is an advantage since the plants are exposed to the hazards of unfavorable weather for a shorter period. There are also significant differences in cell and tissue structure and arrangement in the stem wall. Lodging-resistant varieties have a thicker band of sclerenchyma below the epidermis and it is fused with the vascular bundles.

Any practice that results in lower light intensity or penetration has a deleterious effect on lodging resistance. Increased nitrogen, closer spacing, and wet season (rather than dry season) planting all make a variety more susceptible because they lead to taller plants, longer basal internodes, and less development and persistence of the leaf sheaths. Of these environmental effects, nitrogen supply is the most important. In varieties susceptible to lodging, the effect of applying nitrogen fertilizer is to lengthen the basal internodes, whereas in resistant varieties any increase in height is largely caused by the elongation which are not critical in lodging resistance.

Transcending in importance all environmental factors, however, is the inherent lodging resistance of the variety.

The New Plant Type

The established varieties of rice in tropical Asia are low-yielding unresponsive to nitrogen, and susceptible to lodging. Moreover, they are of long growth duration, thus limiting the number of crops that can be produced in a year even where irrigation water is available. However, they do have the advantage of grain dormancy and some disease resistance, and the cooked grain is acceptable to Asian consumers. The aim of breeders has been to combine the virtues of the traditional varieties with high yield, nitrogen responsiveness, lodging resistance, and short growth duration.

The relation between plant features, yielding ability, nitrogen responsiveness, and growth duration has been discussed by Tanaka *et al.* (18). In general, the short duration varieties are also those with high yielding ability and nitrogen responsiveness. There is also a relationship between growth duration and plant height (20), the short-statured types being those with a short growth duration. Furthermore, plant height at flowering is inversely related to yielding ability and nitrogen responsiveness. Short varieties also have a larger grain-straw ratio (18).

From all these considerations it is clear that short stature is one of the prime requirements for tropical rice. Other desirable plant characteristics include relatively short, erect, narrow, dark-green leaves to permit penetration and efficient utilization of sunlight (16), and stiff straw to increase lodging resistance.

To achieve the desired plant type, crosses have been made between the short-statured indicas, particularly from Taiwan, and tall indicas from the tropics. Indica x japonica crosses have also been made. It was found that short stature in three Taiwan indicas is conditioned by a single recessive gene, thus allowing this trait to be readily combined with other desirable characteristics.

Success with the new plant types has been immediate and dramatic. So far, the most promising selections have been from crosses between the tall tropical indicas and the short-statured ones from Taiwan. One such selection, known as IR8-288-3, recently topped yield trials in almost every Asian country in which it was tested (10). During the wet season in Thailand it produced over 6 ton/ha., nearly double the yield of the local check variety. Similar wet season results were obtained in the Philippines. During dry season experiments in the

Philippines, the same selection produced over 9 ton/ha. in four separate experiments; in three others it yielded over 8 ton/ha.; and in two experiments the yields exceeded 7 ton/ha. In East Pakistan, India, and Malaysia the selection produced in excess of 6, 10, and 6 ton/ha. respectively.

One of the most striking features of IR8-288-3 is its nitrogen responsiveness. This is illustrated in fig. 2 taken from a dry season experiment in the Philippines (9). The selection recorded increased yields from each increment of nitrogen up to 120 kg/ha. Taichung (Native) 1, a short indica from Taiwan, attained its highest yield at 90 kg./ha. The remaining two varieties, Binato and Peta, both tall indicas, responded positively to only moderate applications of nitrogen; heavier dressings resulted in lower yields. This ability to respond to high levels of nitrogen presents the Asian farmer, virtually for the first time, with the opportunity of lifting yields substantially with the help of large fertilizer nitrogen dressings. On some soils, however, the new selection produces at least as well as the commonly grown varieties, even without added nitrogen.

IR8-288-3 is susceptible to several diseases and there is room for improvement in grain quality. Later strains now being developed will doubtless have better grain quality and more disease resist-

ance. In the meantime, because of its enormous yield potential, the selection has been distributed widely in Asia for further testing and seed multiplication (11).

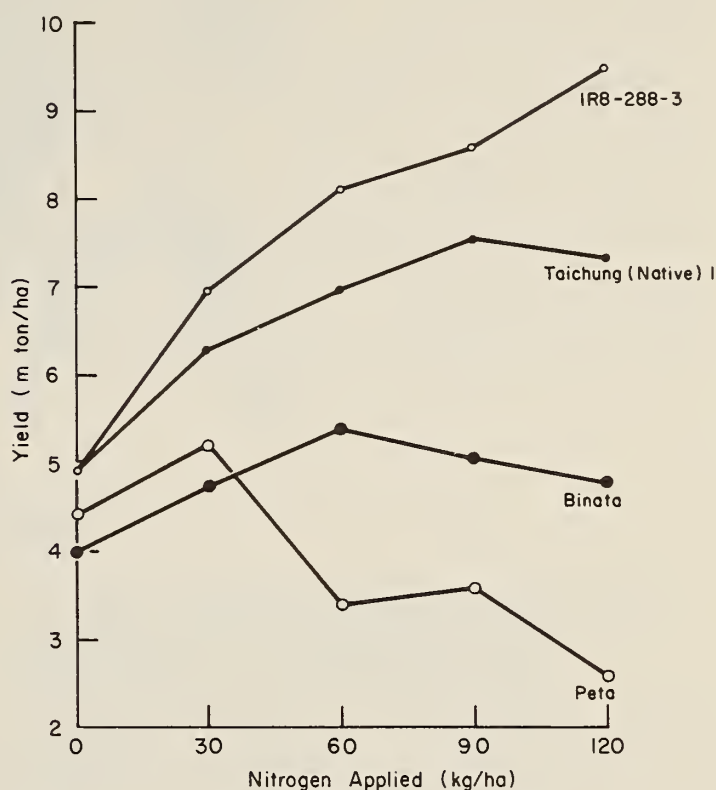


FIGURE 2.—Grain yield response of four rice varieties during the 1966 dry season in the Philippines.



New varieties will achieve nothing if the crops are eaten by rats, destroyed by insects, or withered by disease. Furthermore, on most soils they will not realize their potential yield without adequate fertilizer and water control. But unless the plant itself has a high yield potential no amount of plant protection, fertilizer, or improved farming techniques will guarantee big yield increases. Also, to convince the Asian rice farmer to change his ways it is probably essential to offer him dramatic, rather than marginal, yield increases. Such increases will simultaneously make many pest control, fertilizer, and other modern procedures economically feasible.

The new varieties now being developed with yield potentials severalfold those of the established ones offer real possibilities of increasing Asian rice yields substantially and making an impact on the Asian food situation. It may be calculated, for example, that if 15 percent of the rice lands of India could be induced to yield 2 ton/ha more than at present the existing 10 million ton food grain deficit would be eliminated. In the Philippines, an extra one ton per hectare from 10 percent of the rice lands would convert a rice-importing country into an exporting one. Experimental results have shown that yield increases of at least these amounts are possible with the new short-statured selections.

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Present Status and Future of PLANT REGULATING SUBSTANCES

JOHN W. MITCHELL

Beginning with the first practical use of plant-regulating substances—the stimulation of root formation—the importance of these chemicals for plant production in the United States has steadily increased. As new uses have been discovered, their commercial production has expanded. For example, nearly 1 million pounds of 2,4-dichlorophenoxyacetic acid, a compound that first attracted interest because of its growth-regulating properties, was produced in 1945. Present output is 53 million pounds each year—practically all of which is used for control of weeds. The amount of this acid used for stimulating plant growth and controlling plant behavior, along with all other regulating substances used for these two purposes, is insignificant in comparison with the amount of the phenoxy acid used for weed control, because only minute amounts are required to induce the desired effects. All of these substances, however, have a definite value in the production of certain plants in the United States.

By May 1966, the Pesticides Regulation Division of the U.S. Department of Agriculture had ap-

proved 34 growth-regulating chemicals for 92 different uses in crop production. These uses include both the stimulation of plant growth and the control of plant behavior in ways that make crops better suit our needs.

GROWTH ACCELERATION

Acceleration of Fruit and Bud Growth

One of the most important uses of regulating compounds for growth acceleration is in the culture of Thompson Seedless grapes, which are raised extensively in California. Histological studies show that during the growing season there is a general increase in cell diameter in an interior band of tissue throughout the pericarp of the grape. This condition accounts mainly for the increase in volume of the grape.

When gibberellin A_3 or auxin is applied to the fruit, enlargement of the grape is accelerated because of increased growth of cells in this interior band of tissue (62).¹ The accelerating effect of the gibberellic acid is expressed early in the develop-

This article was adapted from Dr. Mitchell's invitation paper presented at the Symposium on Plant Stimulation held at Sofia, Bulgaria, October 25-30, 1966. Proceedings of the symposium will be published by symposium officials in 1967.

¹ Italic numbers in parentheses refer to Literature Cited p. 33.

ment of the grape while later growth is influenced very little.

Five years after the first experiments that demonstrated growth stimulation of grapes with gibberellic acid (73), almost all table grapes of the Thompson Seedless variety grown in the United States were being sprayed with this acid to improve their size and quality. Girdling is also used in conjunction with gibberellic acid to obtain the largest berries.² Even though the grapes are thinned, many of the clusters are often very compact and subject to rot because of fungal infections. During 1965, however, it was discovered that gibberellic acid, applied as a spray at bloom, stimulated growth and caused the plants to produce very loose clusters with large, elongated berries (75). About 25,000 to 35,000 acres are sprayed each year for this purpose, and it is predicted that in the near future practically all Thompson Seedless grapes for table use will receive this spray treatment.

Most Black Corinth grapes, a variety important in the production of raisins, were sprayed with 4-chlorophenoxyacetic acid to replace the girdling operation until the advent of gibberellic acid. Gibberellic acid induces the plants to produce relatively large berries. It is also used to a lesser extent to accelerate the growth of wine grapes to make the clusters loose and more resistant to fungal diseases.

Tukey, Fleming, and Cassino (71) used the retardant N-dimethylamino-succinamic acid experimentally to control berry clusters of Concord grapes. When this regulator was sprayed on the vines at the time of bloom, the weight of grapes per 100 clusters and the average number of berries per cluster increased, but the average weight per berry decreased. The chemical had no significant effect on the percent of total soluble solids.

Very recently, kinins were found to accelerate experimentally the growth of some kinds of grapes (76). Application of 6-(benzylamino)-9-(2-tetrahydropyranyl)-9H-purine and benzyladenine as sprays to the entire vine effectively increased fruit number and, in some instances, fruit growth. These responses were obtained with various grapes including Black Corinth, Thompson Seedless, Muscat of Alexandria, Tokay, and Almeria (Ohanez). The application of purine to Black

Corinth clusters at bloom induced the berries to grow almost 3 to 4 times larger than those that developed on untreated clusters. The compound also induced berry development on emasculated flowers of Black Corinth, Thompson Seedless, and Tokay varieties.

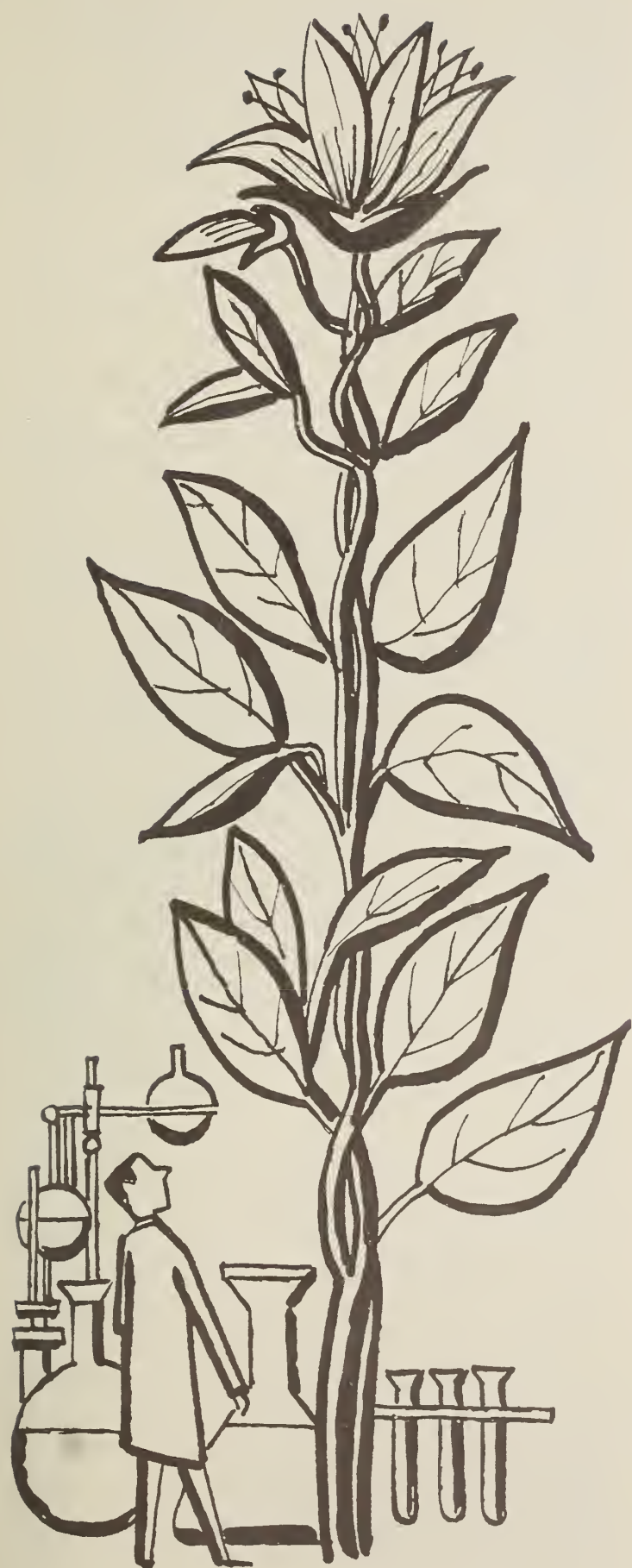
Weaver and Pool have detected naturally occurring gibberellin-like substances in various varieties of grape (74). Although the exact function of these hormones is not known, their action may be controlled or supplemented by the addition of exogenous gibberellic acid in a way that accelerates berry growth.

Beta-naphthoxyacetic acid has been used commercially to increase the number of fruits developed by the first flower cluster of field-grown tomato plants. In addition, gibberellic acid, when used experimentally, stimulated growth, flowering, and fruit set of Earlypak tomato plants. Both the fresh and dry matter content of the young plants was significantly increased (57).

Although growth of tomato plants has been accelerated with gibberellic acid, the hormone has a different effect on growth of the fruits. The acid reversed the inhibiting effect of far-red light on tomato fruit development and increased the number of fruits of the Marglobe variety that developed under conditions in which the fruits are usually dormant (34, 35). On the other hand, even repeated treatment under field conditions failed in some instances to increase tomato fruit size and, in some experiments, the fruits were smaller than those that developed on plants that were not sprayed with the acid (56, 78).

Retardant chemicals were recently used experimentally to control fruit production and improve fruit quality of tomato plants. Using a mid-season processing variety (Delaware 65S3-2), Read and Fieldhouse (61) applied a 2,500-p.p.m. solution of N-dimethylaminosuccinamic acid when the plants were at the first true-leaf stage. Yields were 25 to 30 percent higher than those of untreated plants. Application of the acid to the plants at other stages during their development was also effective. Fruit size was similar to or slightly larger than that of fruits from untreated plants. Fruit firmness was increased and the color of fruits from the treated plants appeared to be intensified. A second retardant compound (2-chloroethyl) trimethylammonium chloride, also increased yield and

² Personal communication from R. J. Weaver, Univ. of Calif. 1966.



stimulated the onset of bloom with the result that flowering occurred up to 7 days earlier than in untreated plants.

Retardant chemicals have not been approved as yet for use on edible crops in the United States. Studies are now underway, however, to determine whether these substances can be safely used to control the growth and behavior of plants used for food.

Growth of white potatoes has been stimulated, under some conditions, by the application of gibberellic acid. This acceleration is evident in the promotion of sprouting, hastening of emergence, and shortening of the rest period by 2 to 3 weeks with such varieties as White Rose, Kennebec, and Russet Burbank (27, 33, 58, 68, 70).

Freshly harvested tubers treated with gibberellic acid and replanted immediately produced higher yields than comparable untreated tubers. This growth acceleration was associated with earlier emergence and maturation of tubers that developed on plants grown from the treated seeds than from untreated ones (70).

The value of gibberellic acid in promoting higher tuber yields is limited, however. Since it is only with resting seed potatoes that this acid treatment resulted in increased tuber yield, application of gibberellic acid is not recommended as a general cultural practice (69).

Since exogenous gibberellic acid can alter the rest period of potatoes and, under some conditions, accelerate potato bud growth, scientists have searched for naturally occurring gibberellin-like hormones which might participate in the control of the rest period of potato tubers. About 5 years ago, gibberellin-like substances were detected in Irish potatoes (51, 64). Some of these substances appeared to be different from the known gibberellins, since they were detected in neutral extracts from potatoes, while the known gibberellins are obtained by extraction under acid conditions (21). In support of the hypothesis that endogenous gibberellin-like substances influence growth of potatoes, Smith and Rappaport (63) found that these hormones were present in low amounts during the rest period of tubers but increased up to 30-fold as the tubers began to sprout.

Recent research affords some insight into possible ways in which these potato hormones behave. A gibberellin-like substance obtained by chemically neutral extraction of potatoes possessed relatively

low activity. This factor became acid during storage and showed biological effects that were qualitatively and quantitatively different from the compound originally extracted. This behavior indicates that bound forms of gibberellins or gibberellin-like substances may exist in potatoes (22).

Both gibberellic acid and ethylene chlorohydrin have been used to break the dormancy of potato buds. Bonner and co-workers (67) showed that chromatin from dormant potato buds was inactive when tested for template activity. However, after treatment with ethylene chlorohydrin, the template activity of dormant potato chromatin was greatly stimulated. Very recently, Rappaport and Stahl (59) reported acceleration of DNA and RNA synthesis in dormant potato buds treated with gibberellic acid.

Although a question has been raised as to whether the inhibitor beta complex plays a part in the rest period of potatoes, recent experiments with this complex show that it can retard potato bud growth and that this retardation can be reversed through the application of gibberellic acid A_3 (7, 8, 23).

Since gibberellic acid A_3 induces growth of potato buds under certain conditions and accelerates elongation in stems, it would be expected that such responses require compounds which function as building blocks in connection with this growth. Clegg and Rappaport (14) recently found evidence that gibberellic acid responses in the tubers are associated with enzymatic activity which supplies certain of the building blocks. Cylinders of potato tissue treated with gibberellic acid decreased in sucrose content and, at the same time, there was an increase in glucose and fructose sugars, suggesting that invertase may have been involved. They also observed that glucose increased somewhat more rapidly than fructose, indicating that other enzyme systems may also have been involved.

Hormone control of potato growth is an active field of research in the United States. However, investigators in this area stress that they are far from a clear understanding of hormone control, from the standpoint of both acceleration and inhibition of potato growth.

Acceleration of Flower Initiation and Development

Biannual bearing, or the production of heavy crops of fruit such as apples every other year, is due to

failure of the trees to produce a maximum number of flowers annually. Flower development on Delicious apple trees was experimentally controlled through the use of a growth retardant, N-dimethylaminosuccinamic acid (5). Extensive experiments indicate that trees sprayed with this retardant may have two to three times more blossoms the following year than do unsprayed trees. The compound also appears to have promoted development of flower buds when sprayed on trees of the McIntosh variety (20).

N-dimethylaminosuccinamic acid is readily absorbed and translocated in the tree and, once absorbed, the regulator is very slowly metabolized by the plant (18, 41). For example, Edgerton and Greenhalgh report that, within 24 hours after spraying, the quantity of the acid detected on the surface of the fruit was reduced by one-half and considerable quantities of the compound were found in both flesh and seeds. The compound accumulated mainly in the flower buds and vegetative buds, and the chemical was relatively persistent in the fruits and dormant buds.

Although the mechanism of action of this chemical is not understood, the response of accelerated flower production may prove to be of decided benefit in correcting alternate bearing.

It has been known for some years that the yield of Bartlett pear trees can be increased to some extent through the use of 2,4,5-trichlorophenoxypropionic acid. The effect of this acid is to increase the number of flowers that develop fruit (fruit set) as a result of spray applications during the bloom period. Concentrations of 50 to 100 p.p.m. were relatively effective on Bartlett pears (17). More recently, increased fruit set of Anjou pears was obtained experimentally with sprays containing 5 to 10 p.p.m. of this acid (16).

At present, some research is being conducted in Oregon on the use of gibberellic acid to improve fruit set of some varieties of pears. This research also includes a study of the effectiveness of this chemical when used to improve fruit set of pear trees that have been damaged by frost.

Retardant chemicals have recently been used experimentally, and to some extent in a practical way, in the United States to control growth and flowering of some kinds of ornamental plants (10, 11, 36, 62). For example, some varieties of azalea and rhododendron are made to flower when desired through the

use of suitable chemical treatments in combination with appropriate temperature and photoperiods. Young holly plants have been made to develop flowers in one year instead of two.

One of the most recent advances in the control of ornamental plants involves the use of naphthalene-base oils, which are aromatic fractions obtained from petroleum distillations. In experiments by Cathey *et al.* (12), these oils had a selective effect on the bud growth of chrysanthemums, depending upon the stage and rate of flower initiation, the type of cultivar, and the surfactant used to emulsify the oil. For example, treatment of vegetative plants caused death of the apical meristem. On the other hand, spray applications caused abortion of the lateral flower buds only when treatment was applied after terminal flower buds had completed flower initiation but before lateral flower buds had initiated all of the florets. This amounted to chemical pruning of the lateral buds since they failed to develop, while the terminal buds were unaffected and developed at the usual rate.

In another recent example of experimental growth control, by Stuart (66), the fatty acid derivatives, methyl nonanoate and methyl decanoate, were used to induce "chemical pruning" by killing terminal shoot tips of greenhouse azaleas without injury to foliage or axillary buds. The treatment stimulated new growth. The retardants, 2-chloroethyl trimethyl ammonium chloride and N-dimethylaminosuccinamic acid, can be used as foliar sprays to inhibit further shoot growth of the azaleas and cause the plants to initiate flower buds. Short photoperiods after application of the retardants, together with cool temperature (50° F.), after bud development accelerate flowering. Thus, it appears that floriculturists now have very useful chemical tools which, when used with appropriate photoperiod and temperature conditions, afford a wide range of control over the growth and flowering of some kinds of ornamental plants.

Acceleration of Protein Synthesis

Since growth acceleration generally involves, directly or indirectly, hormone control of growth processes and synthesis of new proteins, a brief account of current research in this area is given here. The biochemistry of hormone regulation of growth processes in plants is now the subject of extensive

studies in many laboratories across the United States. Recent investigations using both animal and plant tissues clearly demonstrate the requirement of RNA and protein synthesis in the final expression of hormone action (67). Current research in this field is directed toward understanding the primary step, at the molecular level, involved in hormone action. The ultimate aim is to control hormones in ways that will give us plants that better suit our needs.

Among all hormone-controlled physiological changes in plants, there is one well-known example involving enzyme synthesis. This is the production of alpha-amylase in barley endosperm due to the influence of gibberellic acid or gibberellic acid-like hormones (54). Several reports made during 1960 (52, 53, 79, 80) indicate that seeds of barley produce an amylase-inducing factor as they germinate and that this factor can be replaced with gibberellic acid. The endogenous gibberellin or gibberellin-like substance, an endosperm-mobilizing hormone, is produced by embryos of this seed and secreted into the aleurone layers, causing synthesis of enzymes which move to the starchy endosperm where they liberate nutrient and energy sources necessary for the growth and development of the embryo. Varner and coworkers established that gibberellic acid can control the *denovo* synthesis of alpha-amylase in the aleurone cells (72). Lang and coworkers (49) showed that synthesis of DNA and ribosomal RNA can be accelerated by gibberellic acid in tissues where no cell division and growth occur. In aleurone cells, gibberellic acid stimulates RNA synthesis and a hormone-dependent messenger like RNA fraction has been isolated and characterized (13). In a similar way, a DNA-like RNA fraction from auxin-treated soybean hypocotyl tissue has also been characterized (26).

It has been postulated that gibberellic acid interacts with the nucleus and is involved in the formation of DNA-directed synthesis of messenger RNA (72). Production of a specific messenger RNA for synthesis of a specific protein in response to hormone stimulation, however, remains to be demonstrated. Evidence for the formation of auxin and soluble RNA complexes has been reported (6). The possibility that hormones regulate isozymes is being investigated (50).

While the biogenesis of ethylene is still obscure, some research is being done on the interplay of

auxin and ethylene action (1). Leaf abscission zones have a high rate of protein synthesis and a complex interplay of hormones appears to control leaf abscission (2, 9, 30).

Work is in progress to understand the biochemistry of zeatin-like nucleotide cytokinins (19). Many endogenous growth regulators are currently being detected in plants, and compounds with biological properties similar to abscission II are also being found (2, 4, 25, 28, 47, 48, 60).

In general, we are gaining an understanding of the hormone control of enzyme synthesis and the relationship between hormone action and the growth and behavior of plants. Some of this basic information is already used in a practical way, since gibberellic acid is employed by some members of the brewing industry in the United States to increase alpha-amylase in malt. No doubt more of this basic knowledge will be adapted to practical use in the future.

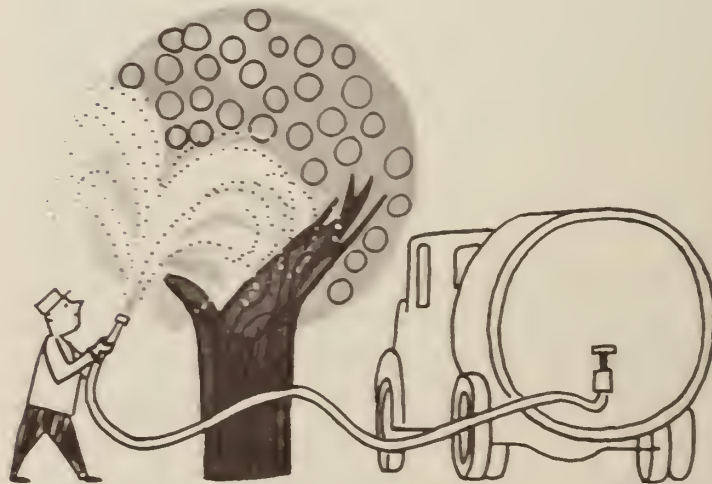
CHEMICAL CONTROL OF PLANT BEHAVIOR

It should be emphasized that plant regulating compounds are used in the United States mostly to control the behavior of plants rather than stimulate their growth. Used in this fashion, they are of considerable value in certain areas of American agriculture. For example, the quality of such fruits as apples and pears is improved with regulators that make these fruits remain on the trees until the appropriate harvest period. The high cost of thinning fruits by hand makes it almost essential that chemical thinners be employed. The storage quality of potatoes throughout the United States is improved by chemically inhibiting bud growth on the harvested tubers. Potatoes treated to improve their storage behavior in this way are processed as potato chips of high quality. The fruitfulness of sour cherry trees infected with the cherry-yellows virus can be increased and the appearance of navel oranges can be improved through the application of gibberellic acid (15, 55). Regulating substances are also used as an aid in vegetative propagation of plants but, as mentioned before, the greatest amounts of regulating compounds are used to control weeds. With this diversity of useful effects, the importance of regulating chemicals in crop production seems to be well established.

PROBLEMS AND POSSIBILITIES

New ways of advantageously controlling plant growth and behavior with hormones and regulators are sure to be discovered. There is the basic requirement, however, that chemical agents used for this purpose must not be harmful to man or adversely affect his environment. To prove that a new regulating substance meets this requirement is very costly. If regulators could be obtained from plants that are used for food, it might be assumed that these substances would be relatively nontoxic. With this in mind, some scientists are studying certain edible plants as a possible source of hormones with which to further control the growth and behavior of crop plants. However, many of those studying hormones of higher plants are interested in the action of hormones rather than in finding sources of new regulators. At present, no hormones have been obtained from higher plants in amounts suitable for determining their usefulness in agriculture in the United States.

Among the unsolved problems, is a need for hormones that will accelerate growth and increase productivity of plants. Some experimental results indicate that we have not yet fully utilized the potentialities of regulators for growth acceleration. For example, when minute amounts of 2,4,5-trichlorophenoxyacetic acid were sprayed experimentally on soybean plants in full bloom, the regulator indirectly brought about increased yield by causing the flowers to abscise. The plants then developed new flowers in greater numbers than before, and at the end of an extended growing period produced a much larger crop (40). Growth acceleration was obtained experimentally by spraying



gibberellic acid A₃ on young loblolly pine trees growing in a greenhouse. At the end of the following year, the stems were twice as thick as those of the untreated trees (3). Growth acceleration was also obtained with willow oak and yew (*Taxus*) under greenhouse conditions (38). Acceleration of stem growth was obtained experimentally by applying gibberellic acid to young cocoa trees growing in a greenhouse. Growth of xylem in the treated area of the stems was greatly increased, while growth of phloem was only slightly affected (43). None of these examples of growth acceleration has as yet proved to be of practical significance. The responses cited indicate, however, that we have not fully utilized the backlog of information about regulating compounds for directly or indirectly accelerating growth of some kinds of herbaceous and woody plants.

Methods of obtaining useful hormones economically from plants are needed. Some possible sources that are plentiful and which contain hormones of the gibberellin type are: cotton and potato plants, pollen of corn, and seeds of bean and barley (24, 45, 46, 51, 64, 77).

Also needed is a chemical means of controlling protein synthesis by plants. Production of amylolytic enzymes in leaves, aleurone layers of seeds, and stems has already been accelerated through the use of regulating substances (42, 44, 54). These results suggest the possibility that regulators may be used more widely in the future for controlling the production of some proteins or enzymes by plant cells.

On the other hand, methods of control that do

not directly involve growth acceleration would be useful. For example, regulating substances to retard the growth of ornamental grasses under a variety of conditions would reduce maintenance cost and aid in erosion control. Highly productive small plants, grown with chemical retardants, might prove to be advantageous in the mechanical harvesting of such crops as tomato and some kinds of fruit.

Hormones that control the maturity of crops are needed in order to shorten or space harvest periods advantageously. Hormones and regulating substances that will increase the resistance of plants to adverse environmental conditions, particularly low temperatures, are important, since these would reduce losses and make it possible to grow such crops as citrus and peaches over wider areas. Some growth-regulating substances have been used experimentally to increase the resistance of plants to frost and other adverse conditions (29, 37, 39).

Regulators are needed to safely retard the ripening of harvested fruit in a way that will improve storage behavior without impairing quality. Possibilities in this direction are evident in the work of Lieberman and coworkers (31, 32), who have demonstrated the anti-ripening and anti-aging effects of ethylene oxide.

It is obvious from these examples that the potentialities of known responses, other than growth acceleration, also need to be explored fully.

Current progress in the use of growth regulators and in understanding how they function is encouraging as we undertake the solution of some of these challenging problems.

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FORUM

A COLLOQUY ON ENTOMOLOGY AND ECONOMICS

We are convinced that a closer association between economists and entomologists would be productive. But, unfortunately, the increasingly technical aspects of each of the biological sciences tend to discourage sorties into them by the social scientist. The hindrances arise no matter how the joint problems are approached. Just as an entomologist would be at a disadvantage in, say, evaluating the export potential of soybean oil, so would an economist be hard put to assess the damage potential of a new pest or the probable efficiency of a biological control agent.

It is hardly necessary to narrate here a detailed list of achievements in entomological research. Obviously, these achievements have been significant. At least we can say that insects pose no major threat to the human race as does, for example, the control of atomic weapons or the population explosion. But the widely ranging scope of entomological effort has introduced difficult and important problems of evaluation. What are the cost benefits, or, more properly, what is the cost effectiveness of a multiple-disciplined approach to research? What guidelines can administrators use to properly allocate available funds to the various lines of entomological research or between entomology and other fields of research?

Historically, entomologists have attempted to achieve as near perfect control of insects as it is possible to obtain. This may not be necessary. A less effective chemical or biological control agent may be more economical than the apparent best

method. But how do we know for sure? It is probable that more progress could be made along cooperative lines of research if economists were able to digest entomological literature, and if entomologists would consult with them to see what kinds of data would be useful for analysis.

A comparison of the dollar-and-cents benefits of insect control with the costs of such control is the principal tool an economist brings to the task of appraising entomological activity. Entomologists have, in fact, been more aware of these economic aspects of their work than many other biological scientists. They frequently compare the costs of bringing some insect pest under control with the actual or potential losses caused by the infestation.

Economic Evaluations

The development of DDT was one of the most spectacular successes in the war on insects. First synthesized in 1874, its effectiveness as an insecticide was discovered in 1939 by Paul Muller, a Swiss. DDT possesses unusual residual properties; spraying a building protects against the malarial mosquito for several months. It is also effective against lice and fleas that spread typhus and plague. Spraying with DDT has been widely practiced throughout the world and the resulting degree of control over malaria, typhus, and plague may be considered one of our great public health achievements.

Despite the obvious success of this control, economic assessment of the benefits is virtually impossible. How does one value human life and health? In the affluent nations, very large sums are spent for public health improvement, but in most of the world, medical attention is virtually unknown to much of the population. Suppose we consider, now, an offsetting factor in the assessment of benefits. DDT and similar measures have drastically reduced death rates since World War II. But population growth has offset much of the gains one might expect from the medical triumphs. In much of the world, population growth still presses on food supplies; industrial progress is slowed; and standards of living remain desperately low.

In August 1965, USDA published estimates of annual average losses during the 1950's for crops, livestock, and forest products. A rough sorting of the losses and control costs relating to insects is shown in Table 1.

A major limitation of Table 1 is that it measures losses rather than benefits. In the absence of the control efforts which were made, it is certain that the depredations of the unchecked insects would have been several times as large as the losses which did occur. The estimated losses are more nearly related to the further benefits which would accrue from further control efforts. Obviously there is still room for a handsome return on controls. However, it is also clear that expansion of control efforts should not be carried to the point where they exceed the average annual losses.

A second limitation of Table 1 is that loss estimates were computed at market prices. The authors point out that in any successful wide-scale control program, the larger quantities produced and marketed result in depressed prices. In this respect, insect control is like other forms of agricultural science.

The control costs estimates did not include the costs of entomological and chemical research. Consider this fact: In 1963 public-supported research effort consisted of 426 man-years at State experiment stations and 436 man-years within the Agricultural Research Service of USDA. To these figures we should add 101 man-years of forest insect research. If we can assume that, at that time, each man-year cost \$26,000 to \$30,000 inclusive of laboratory facilities, supervisory, and other support—the total research cost would be about \$27 million.

Examples of Costs and Benefits

Some battles against insects are fairly easy to assess. In a New York State campaign against the Mexican bean beetle, savings were listed at \$3,014,094 and expenditures for insecticides and the labor to apply them at \$785,162 for a benefits-cost ratio of 3.8. Presumably the benefits were computed by multiplying going market price by the quantity estimated to be saved by the control measures. Since New York State production constituted less than 10 percent of the U.S. total, it was probably appropriate to use the market price.

The story of biological control of Klamath weed in northern California has been cited as another favorable cost-benefits comparison. Effective control of this weed by the use of insects has obviated the need for previously applied chemical treatments; annual savings are estimated at \$160,000. This effective control has been accompanied by a dou-



bling of land values as the range improved and cattle-carrying capacity increased. During a 7-year period, savings have been estimated at \$8,960,000. This figure is double the total budget for biological control research in California for the 36 preceding years, during which time other equally impressive results have been obtained with biological control of other pests.

A recent study determined the value of alfalfa in a dairy economy. Involved in this evaluation were the competitive position of the crops under consideration, frequency and cost of treatment, yield potential level of infestation, degree of control necessary, and other factors. Results of this study indicated that \$10 an acre could be spent profitably for insect control on alfalfa, the principal pest of which is the alfalfa weevil. Although present chemical control methods do not exceed this figure, the study provides a guideline for assessing the potential of other techniques, or for planning large-scale control or eradication programs.

Basic Research

Benefits-cost estimates, of course, cannot be neatly applied to proposals for basic research. It is a characteristic of basic research that the investigator does not always know what specific applications may result. He is extending the frontiers of knowledge. To be sure, he may be aware that knowledge of the life cycle of some destructive pest may help determine when, how, and with what to spray or may indicate what micro-organisms would be the most promising means of control. However, no reasonable calculation of benefits is possible at the basic research stage of investigation.

Future Collaboration

One major result of this colloquy between entomologist and economist is that the economist's tool of benefits-cost comparison has its limitations and should be used with great restraint. This caution reflects these salient facts: (a) the human benefits of disease control and more comfortable living are hard to quantify; (b) the results of basic research cannot be known at the time; and (c) benefits to all segments of the economy should be included rather than confining the calculation to farm income. For example, when the effectiveness of organic insecticides became well known, an economist might well have concluded that entomological research should be heavily concentrated in this low-cost, high-benefits area. But the subsequent appearance of insect resistance and of residue problems would shortly have sent us back to the basic research approach and to all the other lines of attack that are being developed.

Collaboration could, however, be highly fruitful in research planning and performance. The possibilities are well exemplified by the current status of the aforementioned research on the alfalfa weevil.

Two factors should aid in achieving further collaboration. One is that 20 percent of the Federal funds provided under the amended Hatch Act must

be allocated to marketing. Since marketing is such a prominent part of economics, more emphasis might be given to entomologist-economist team studies at the experiment stations. A second, more recent development to spur collaboration is the emphasis on the Planning-Programming-Budgeting System—a new approach to the Federal budgeting process. Essentially, this system requires a quantitative estimate of the benefits from each item of proposed expenditure. Under it, a research project would be funded only if the prospective benefits exceed the costs. Furthermore, the benefits and costs of alternative actions would be considered whenever possible.

Decisions, of course, cannot be made on an economic basis alone. The entomologist and economist must consider the issues jointly. Such factors as the potential development of insect resistance, the possibility of residues, and the probability of research success on resistant varieties—all should be considered. Much of the published research compares effectiveness of control measures under various conditions, but estimated costs of the controls are too seldom specified.

R. E. Freeman, Economic Research Service

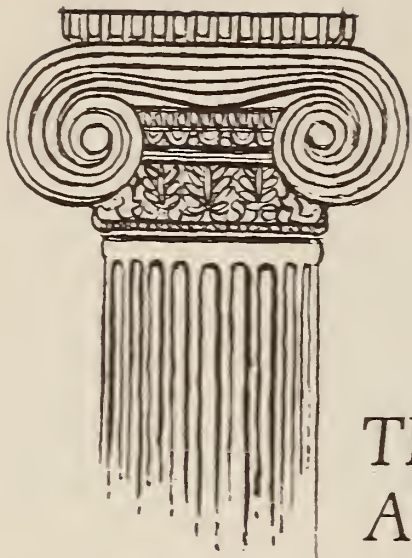
D. R. King, Cooperative State Research Service
U.S. Department of Agriculture

TABLE 1.—*Estimated annual average losses to agricultural commodities from insects and control costs, 1951-1960*

Kinds of loss and control	Loss in value	Cost of control
	<i>Thousands of dollars</i>	
Crops, pasture, and range plants	3, 812, 406	425, 000
Livestock and poultry	877, 850	
Forest products	500, 000	
Forest	57, 380	3, 450
Honey bee losses	500
Stored products	856, 849	279, 302
Other ¹	19, 850
Totals	6, 104, 985	727, 602

¹ Pest control and quarantine programs.

Source: *Losses in Agriculture*—USDA Agr. Handbook No. 291, Aug. 1965.



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